Laboratory for Atmospheres

PHILOSOPHY, ORGANIZATION, MAJOR ACTIVITIES, AND 2000 HIGHLIGHTS

National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771

NASA GODDARD SPACE FLIGHT CENTER

Laboratory for Atmospheres

PHILOSPHY, ORGANIZATION, MAJOR ACTIVITIES, AND 2000 HIGHLIGHTS

January 2001

Terra, the flagship spacecraft of NASA's Earth Observing System (EOS). Terra was launched in December 1999 and had a successful first year of operations during 2000. Terra is an international project, involving NASA centers, NOAA, NRL, universities, and industry. Two of the instruments were built abroad: ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), in Japan, and MOPITT (Measurements of Pollution in the Troposphere), in Canada. Terra has five state-of-the-art sensors for studying interactions among the Earth's atmosphere, lands, and oceans. The EOS senior project scientist is Michael King, Code 900. The Terra project scientist was Yoram Kaufman of Code 913 until September 2000, when the position was taken over by Jon Ranson of Code 923. The deputy Terra project scientist is Si-Chee Tsay of Code 913. (For further information on Terra, see the Terra Web site at http://terra.nasa.gov/.)

Earth, a composite image of the first full day of data taken April 19, 2000, from the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra. Vincent Salomonson, Code 900, is the MODIS science team leader. The science team is composed of four groups: atmosphere, calibration, land, and ocean. Robert Murphy, Code 900, is the MODIS project scientist. Michael King of Code 900 is the group leader of the atmosphere group, and Yoram Kaufman (Code 913) is one of the members. Scientists in our Laboratory use data from MODIS and the other Terra instruments to study regional and global-scale changes in clouds, aerosols, fires, and other features of the Earth's system that affect our atmosphere. A few of these studies are discussed in the Highlights section of this report. (For further information on MODIS, see the Web site at http://modis.gsfc.nasa.gov/.)

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

Laboratory Chief's Summary

January 2001

Dear Reader:

Thank you for taking the time to acquaint yourself with the Laboratory for Atmospheres and our accomplishments for 2000!

The Laboratory consists of 375 scientists, technologists, and administrative personnel working within the Earth Sciences Directorate of NASA's Goddard Space Flight Center. Together, we are dedicated to our mission of advancing the knowledge and understanding of Earth's atmosphere and the atmospheres of other planets. In doing so, we contribute directly to two of NASA's primary activities, the Earth Science and Space Science Enterprises.

We publish this report each year for a diverse group of readers— from our managers and colleagues within NASA to scientists outside the agency, from graduate students in the atmospheric sciences to members of the general public. Inside, you'll find descriptions of our philosophy, our people and facilities, our place in NASA's mission, and our accomplishments for 2000.

We had a busy year. Laboratory staff hosted 75 seminars, conducted 18 workshops and science team meetings, published 202 refereed papers, hosted 155 short-term visiting scientists, and participated in an array of educational activities. Our scientists played leading roles in mission and science activities. We had nine project scientists and four deputy project scientists for spacecraft missions, one EOS validation scientist, and seven co-project or mission scientists in field campaigns. I want to thank Yoram Kaufman for having served as project scientist on EOS Terra. I also want to thank Chris Kummerow for having served as project scientist on TRMM, and Paul Newman and Mark Schoeberl for serving as both mission planners and project scientists on SOLVE.

Among our many workshops and seminars, I am pleased to mention the Workshop on Relationships and Intercomparison of Monsoon Climate Systems held Nov 28-30 at GSFC. The workshop was hosted by the Laboratory's William Lau (Code 913) and Professor Tetsuzo Yasunari of Tsukuba University in Japan. The workshop provided a forum for scientific exchange and recommended collaborative research projects between US and Japanese researchers through the United States Global Change Research Program (USGCRP), the Japanese Frontier Research System for Global Change (FRSGC), the Global Energy and Water Cycle Experiment (GEWEX), and the Climate Variability and Predictability Programme (CLIVAR). This collaboration is important for increasing our understanding of teleconnection, the climatic connection of global weather systems.

The Laboratory has been active in developing new and improved instruments for spaceflight and for field campaigns. We completed four new instruments this year under the Instrument Incubator Program (IIP). We deployed two improved instruments on the SAFARI campaign, the Cloud Physics Lidar (CPL) and the Surface Measurements for Atmospheric Radiative Transfer (SMART). The CPL, which can measure optical depth, particle size and depolarization is supporting validation of EOS Terra. We also made significant progress on the Neutral Gas and Ion Mass Spectrometer (NGIMS) for the CONTOUR Mission.

The Laboratory had an exciting year participating in international field campaigns. The SOLVE/THESEO-2000 completed its mission in March. SOLVE is a mission sponsored by NASA's Upper Atmosphere Research Program with the participation of national and international organizations. Direct observations from NASA's ER-2 and DC-8 aircraft confirmed that polar stratospheric clouds (PSCs) are key components of the ozone loss process. Our Laboratory played a unique role in this mission, helping to develop mission strategy, providing project scientists, developing and flying some of the experiments, and contributing theoretical studies. SAFARI was a multinational, multi-aircraft campaign in southern Africa. Laboratory members provided *in situ* and remote measurements, data analysis, and theoretical analyses. SAFARI was one of the most aggressive and successful campaigns of its kind ever undertaken. The experiment employed coupled ground-based, *in situ*, and remote-sensing observations to study linkages of land-atmosphere processes and the effects of biomass burning in southern Africa.

In 2000, many Laboratory members earned awards for their outstanding work. Joanne Simpson was nominated for the Charles E. Anderson Award "for her outstanding efforts in promoting diversity within the Society (AMS) and the greater scientific community." Mark Schoeberl won the NASA Distinguished Service Medal for his leadership role in formulating the Earth Science Vision for the Earth Science Enterprise. Yoram Kaufman won the NASA Medal for Outstanding Scientific Achievement and the GSFC Nordberg Award.

The year 2000 was also a time to bid farewell to a number of valuable members of the Laboratory. Chris Kummerow, TRMM project scientist, left to become an associate professor at Colorado State University. We will miss him for all his work on TRMM, but we count on continuing collaboration with him. Robert Theis was my assistant for many years and helped me in many tasks, including this report and moving the Laboratory into our new building. Arlin Krueger, who accepted a professorship at UMBC, had made significant improvements in the TOMS instrument and was principal investigator of ADEOS/TOMS. Patty (Golden) Balanga, one of our Division secretaries and a computer whiz, carried a large share of the burden in producing recent annual reports. Patty is moving on to a new life and a new job across the Potomac. Finally, it is with great regret that we lose Tony Busalacchi to the University of Maryland. As the Chief of the Laboratory for Hydrospheric Processes, Tony helped in creating a positive atmosphere between his Laboratory and mine. Personally, I will miss having him here, although I look forward to close collaboration with him as the head of ESSIC at the University of Maryland.

I am pleased to greet the new members of the Laboratory. In particular, I want to welcome Ron Gelaro and Eric Smith. Ron Gelaro will be working with Bob Atlas in the Data Assimilation Office. Eric Smith is the new Project Scientist for GPM. These newcomers will both add much to the productivity of our Laboratory.

This will be my last report as Chief of the Laboratory for Atmospheres. As of December 31, 2000, I have been the director of the Earth Sciences Directorate for Goddard Space Flight Center. My ten years with the Laboratory have been profoundly rewarding; the caliber of the scientists in each of the branches has made it a pleasure to be at the helm during this decade. I look forward to witnessing the Laboratory's continued success.

Sincerely,

Franco Einaudi

Franco Einaudi, Acting Chief, Laboratory for Atmospheres, Code 910
Director, Earth Sciences Directorate, Code 900
Phone: 301-614-6786
Fax: 301-614-6301
E-mail: franco.einaudi@gsfc.nasa.gov

TABLE OF CONTENTS

1. INTRODUCTION

How can we improve our ability to predict the weather—tomorrow, next week, and into the future?

How is the Earth's climate changing? What causes such change? And what are its costs?

What can the atmospheres of distant planets teach us about our own planet and its evolution?

The Laboratory for Atmospheres is helping to answer these and other scientific questions about our planet and its neighbors. The Laboratory conducts a broad theoretical and experimental research program studying all aspects of the atmospheres of the Earth and other planets, including their structural, dynamical, radiative, and chemical properties.

Vigorous research is central to NASA's exploration of the frontiers of knowledge. NASA scientists play a key role in conceiving new space missions, providing mission requirements, and carrying out research to explore the behavior of planetary systems, including, notably, the Earth's. NASA scientists also supply outside scientists with technical assistance and scientific data to further investigations not immediately addressed by NASA itself.

The Laboratory for Atmospheres (Code 910) is a vital participant in NASA's research program. The Laboratory is part of the Earth Science Directorate (Code 900) based at NASA's Goddard Space Flight Center in Greenbelt, MD. The Directorate itself is comprised of the Global Change Data Center (GCDC), the Space Data and Computing Division (SDCD), and four science laboratories, including the Laboratory for Atmospheres. The three other labs are the Goddard Institute for Space Studies (GISS) in New York, NY, the Laboratory for Terrestrial Physics, in Greenbelt, and the Laboratory for Hydrospheric Processes, also in Greenbelt.

In this report, you'll find a statement of our philosophy and a description of our role in NASA's mission. You'll also find a broad description of our research and a summary of our scientists' major accomplishments in 2000. The report also presents useful information on human resources, scientific interactions, and outreach activities with the outside community.

For your convenience, we have published a version of this report on the Internet. Our Web site includes links to additional information about the Laboratory's Offices and Branches. You can find us on the World Wide Web at http://atmospheres.gsfc.nasa.gov/

2. PHILOSOPHY

As we carry out our work at the Laboratory for Atmospheres, we strive to honor the following values:

Individual Well-being

Personal Freedom

Individuals are free and encouraged to express their views and offer diverging opinions. Laboratory scientists submit research proposals with different technical or technological approaches and, in some cases, may even compete with one another. This freedom promotes creativity, competition, and openness.

Programmatic and Research Balance

Unlike most universities, our Laboratory often has relatively large programs, sizable satellite missions, or observational campaigns that require the cooperative and collaborative efforts of many scientists. We aim to ensure an appropriate balance between our scientists' responsibility for these large collaborative projects and their need for an active individual research agenda. This balance allows members of the Laboratory to continuously improve their scientific credentials.

Research Quality

The Laboratory places high importance on promoting and measuring quality in its scientific research. We strive to assure high quality through peer-review funding processes that support approximately 90% of the work in the Laboratory. The overall quality of our scientific efforts is evaluated periodically by committees of advisors from the external scientific community, as detailed in Appendix 2 of this document.

Scientific Partnerships

Synergy Between Science and Technology

The Laboratory aims to increase its interaction with the Systems, Technology, and Advanced Concepts Directorate (STAAC) and the Applied Engineering and Technology Directorate (AETD) through the formation of joint teams to develop new technologies and engineering solutions for scientific questions.

Goddard offers enormous opportunities for synergy between engineering and scientific expertise. Experimental activities are spread across the Laboratory to foster communication and to maximize the direct application of technology to scientific goals. In addition, a major effort is underway to increase our interactions with engineering groups outside the Laboratory. Healthy collaboration between our scientists and the Center's engineers is vital to our success in the competitive research environment in which we operate.

Interactions with Other Scientific Groups

The Laboratory depends on collaboration with the academic community, with other NASA centers and federal laboratories, and with foreign agencies to achieve its goals. Section 5 discusses some of these relationships more fully. The Laboratory has MOUs (Memorandum of Understanding) with a number of universities for cooperative atmospheric science programs, and has close ties with universities in the area through three centers: GEST (Goddard Earth Science

and Technology) Center with UMBC (University of Maryland Baltimore County) and Howard University; JCET (Joint Center for Earth Systems Technology) with UMBC; and ESSIC (Earth System Science Interdisciplinary Center) with UMCP (University of Maryland College Park).

Support for Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers, the project manager and the project scientist, who are the principal leaders of project management and science respectively.

The project scientist must provide continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Taking on the responsibilities of a project scientist provides a unique opportunity for Laboratory staff to obtain significant scientific management experience. Typically, the Laboratory invites candidates from the senior ranks to fill these roles.

Outreach and Education

Members of the Laboratory interact with the general public to support a wide range of interests in the atmospheric sciences.

Among other activities, the Laboratory raises the public's awareness of atmospheric science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers.

Section 7 presents details of the Laboratory's outreach activities during 2000.

Human Resources

The Laboratory is committed to addressing the demographic imbalances that exist today in the atmospheric and space sciences. We must address these imbalances for our field to enjoy the full benefit of all the nation's talent. To this end, the Laboratory always seeks qualified women and underrepresented ethnic groups when hiring new scientists and technologists. The Laboratory will continue to make substantial efforts to attract new scientists to the fields of atmospheric and space sciences.

Opportunities for the Commercial Sector

The Laboratory fully supports government/industry partnerships, Small Business Innovative Research (SBIR), and technology transfer activities. The Laboratory hopes to devote at least 10% to 20% of its resources to joint activities with industry on a continuing basis.

3. STAFF, ORGANIZATION, AND FACILITIES

Staff

As of this writing, the Laboratory staff consists of 87 civil servants. Of these, 74 are scientists, and 4 are engineers; 69 hold doctoral degrees. In addition, over the past year we hosted 78 visiting scientists (NRC, ESSIC, JCET, USRA, and GEST) and 221 non-civil-service specialists supporting the various projects and research programs throughout the Laboratory.

Laboratory Pictures

LABORATORY FOR ATMOSPHERES STAFF, CODE 910

DATA ASSIMILATION OFFICE (DAO), CODE 910.3

MESOSCALE ATMOSPHERIC PROCESSES BRANCH, CODE 912

CLIMATE AND RADIATION BRANCH, CODE 913

ATMOSPHERIC EXPERIMENT BRANCH, CODE 915

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH, CODE 916

Organization

Figure 1 shows the Laboratory organization.

Laboratory for Atmospheres

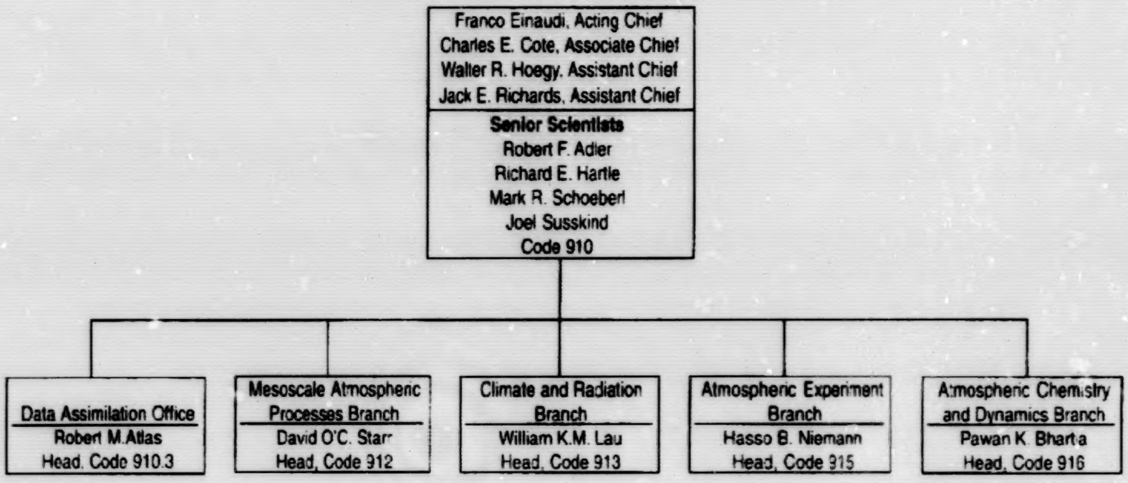


Figure 1. Laboratory for Atmospheres Organization Chart.

Data Assimilation Office (DAO), Code 910.3

The DAO combines all available meteorologically relevant observations with a prognostic model to produce accurate time series estimates of the complete global atmosphere. The DAO performs the following functions:

- Advancing the state of the art of data assimilation and the use of data in a wide variety of Earth-system problems
- Developing global data sets that are physically and dynamically consistent
- Providing operational support for NASA field missions and Space Shuttle science
- Providing model-assimilated data sets for the Earth Science Enterprise

For additional information on DAO activities, consult the World Wide Web (http://dao.gsfc.nasa.gov/)

Mesoscale Atmospheric Processes Branch, Code 912

The Mesoscale Atmospheric Processes Branch studies the physics and dynamics of atmospheric processes, using satellite, aircraft, and surface-based remote-sensing observations as well as computer-based simulations. This Branch develops advanced remote sensing instrumentation (with an emphasis on lidar) and techniques to measure meteorological conditions in the troposphere. Key areas of investigation are cloud and precipitation systems and their environments—from individual cloud systems, fronts, and cyclones, to regional and global climate. You can find out more about Branch activities on the World Wide Web (http://rsd.gsfc.nasa.gov/912/code912/).

Climate and Radiation Branch, Code 913

The Climate and Radiation Branch conducts basic and applied research with the goal of improving our understanding of regional and global climate. This group focuses on the radiative and dynamical processes that lead to the formation of clouds and precipitation and on the effects of these processes on the water and energy cycles of the Earth. Currently, the major research thrusts of the Branch are climate diagnostics, remote-sensing applications, hydrologic processes and radiation, aerosol/climate interactions, seasonal-to-interannual variability of climate, and biospheric processes related to the carbon cycle. You can learn more about Branch activities on the World Wide Web (http://climate.gsfc.nasa.gov/).

Atmospheric Experiment Branch, Code 915

The Atmospheric Experiment Branch carries out experimental investigations to further our understanding of the formation and evolution of various solar system objects such as planets, their satellites, and comets. Investigations address the composition and structure of planetary atmospheres, and the physical phenomena occurring in the Earth's upper atmosphere. We have developed and are constantly refining neutral gas, ion, and gas chromatograph mass spectrometers to measure atmospheric gas composition using entry probes and orbiting satellites. You can find further information on Branch activities on the World Wide Web (http://webserver.gsfc.nasa.gov/).

Atmospheric Chemistry and Dynamics Branch, Code 916

The Atmospheric Chemistry and Dynamics Branch engages in four major activities. The Branch performs the following functions:

- Developing remote sensing techniques to measure ozone and other atmospheric trace constituents important for atmospheric chemistry, climate studies, and air quality
- Developing models for use in the analysis of observations
- Incorporating results of analysis to improve the predictive capabilities of models
- Providing predictions of the impact of trace gas emissions on our planet's ozone layer

For further information on Branch activities, consult the World Wide Web (http://hyperion.gsfc.nasa.gov/).

Facilities

Computing Capabilities

Computing capabilities used by the Laboratory range from high-performance supercomputers to scientific workstations to desktop personal computers.

The supercomputers are operated for general use by the NASA Center for Computational Sciences (NCCS). Their flagship machine is a Cray T3E, with 512 DEC 21064 Alpha microprocessor processing elements, each with 64 Gbytes (Gb) of random access memory. Supercomputer resources are also available through special arrangement from NASA's Ames Research Center's Numerical Aerospace Simulation (NAS) facility.

Each Branch maintains a distributed system of workstations and desktop personal computers. The workstations are typically arranged in large clusters involving 30 or more machines. These clustered systems provide enormous computing and data storage capability, economical to maintain and easy to use. These machine clusters have been acquired to support specific programs, but may be made available for other research on a limited basis.

The Laboratory operates an autonomous ground station for continuously receiving, processing, and serving the Imager and Sounder radiometric data from the GOES satellites. The site also offers recent international geosynchronous satellite data from Japan (GMS-5), China (FY-2), and Europe (METEOSAT-5 and -7). In addition, we are developing a database of full-resolution radiances from India's geosynchronous satellite (INSAT) for the next few years.

Mass Spectrometry

The Laboratory for Atmospheres' Mass Spectrometry Laboratory is equipped with unique facilities for designing, fabricating, assembling, calibrating, and testing flight-qualified mass spectrometers used for atmospheric sampling.

The equipment includes precision tools and machining, material processing equipment, and calibration systems capable of simulating planetary atmospheres. The facility has been used to develop instruments for exploring the atmospheres of Venus, Saturn, and Mars (on orbiting spacecraft), and of Jupiter and Titan (on probes). The Mass Spectrometry Laboratory will also be used in support of comet missions. In addition, the Laboratory has clean rooms for flight instrument assembly and equipment for handling poisonous and explosive gases.

Lidar

The Laboratory has well-equipped facilities to develop lidar systems for airborne and ground-based measurements of aerosols, methane, ozone, water vapor, pressure, temperature, and winds.

Lasers capable of generating radiation from 266 nanometer (nm) to beyond 1,000 nm are available, as is a range of sensitive photon detectors for use throughout this wavelength region. The lidar systems employ telescopes with primaries up to 30 inches in diameter and high-speed counting systems for obtaining high vertical resolution. The Cloud, Aerosol, Lidar, Radiometer Laboratory has specialized facilities for optical instrument development including, optical tables, large auto-collimator, air handlers, and flow bench.

Lidars developed in the Laboratory include the Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL) to measure ozone, temperature and aerosols, the Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE), to measure atmospheric ozone, temperature, and aerosols; the Large Aperture Scanning Airborne Lidar (LASAL), to measure clouds and aerosols; the Cloud Physics Lidar (CPL), to measure clouds and aerosols; the Scanning Raman Lidar, to measure water vapor, aerosols, and cloud water; and the Edge Technique Wind Lidar System, to measure winds.

Radiometric Calibration and Development Facility

The Radiometric Calibration and Development Facility (RCDF) supports the calibration and development of instruments for space-based measurements, for space shuttle demonstration flights, and for new ozone-measurement techniques.

As part of the Earth Observing System (EOS) calibration program, the RCDF will provide calibrations for future Solar Backscatter Ultraviolet/version 2 (SBUV/2) and Total Ozone Mapping Spectrometer (TOMS) instruments. Calibrations were conducted on the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), flying on European Space Agency's (ESA) Environmental Satellite (ENVISAT) mission (2001); ODIN Spectrometer and IR Imager System (OSIRIS), on the Canada/Sweden ODIN mission (2001); and the Israeli Mediterranean Israeli Dust Experiment (MEIDEX) shuttle instrument (2001). The facility also is the home of Compact

Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) (IIP) and Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE).

The RCDF contains state-of-the-art calibration equipment and standards traceable to the National Institutes of Standards and Technology (NIST). Calibration capabilities include wavelength, linearity, signal to noise (s/n), instantaneous field of view (IFOV), field of regard (FOR), and goniometry. The facility is also capable of characterizing such instrument subsystems as spectral dispersers and detectors.

The Facility includes a class 10,000 clean room with a continuous source of N_2 for added contamination control.

4. OUR WORK AND ITS PLACE IN NASA'S MISSION

NASA's Enterprises

NASA's overall program, as outlined in the agency's strategic plan, is composed of five enterprises:

- Earth Science
- Space Science
- Aerospace Technology
- Biological and Physical Research
- Human Exploration and Development of Space

The Laboratory for Atmospheres concentrates on two of these, the Earth Science and Space Science Enterprises.

Earth Science

The mission of NASA's Earth Science Enterprise (ESE) is to develop our understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. Within this enterprise, the Laboratory for Atmospheres addresses both short-term weather forecasting and long-term climate studies. The wide array of our work reflects the Laboratory's history of atmospheric research, from the early days of weather satellites and emphasis on weather forecasting to our present focus on global climate change. Our goal is to increase the accuracy and lead-time with which we can predict weather and climate change.

In support of the U.S. Global Change Research Program and the U.S. Weather Research Program, the Earth Science divisions of the Earth Science Enterprise have established certain priorities:

- Atmospheric Chemistry
- Biology and Biogeochemistry of Ecosystems, and the Global Carbon Cycle
- Climate Variability and Prediction
- Global Water and Energy Cycles
- Solid Earth Science

The Laboratory for Atmospheres conducts basic and applied research in most of these priority areas.

Specifically, Laboratory scientists focus their efforts on the following areas:

- Aerosols and radiation
- Atmospheric hydrological processes
- Atmospheric ozone and trace gases
- Climate variability
- Mesoscale processes

Our work involves four primary activities or products: measurements, data sets, data analysis, and modeling. Table I depicts these activities and the topics they address.

Table I: Laboratory for Atmospheres Earth Science Activities

Measurements	Data Sets	Data Analysis	Modeling
Space	DAO assimilated products	Aerosols	Atmospheric chemical
Aircraft	Global precipitation	Climate variability and climate change	Clouds and mesoscale
Balloon	TOMS aerosols	Clouds and precipitation	Coupled climate/ocean
Ground	TOMS surface UV	Global temperature trends	General circulation
Field campaigns	TOMS total ozone	Ozone and trace gases	Radiation transfer
	TOVS Pathfinder	Radiation	Retrievals and data assimilation
	TRMM validation Products	UV-B measurements	
		Validation studies	

The divisions among measurements, data sets, data analysis, and modeling are somewhat artificial, in that activities in one area often affect those in another. These activities are strongly interlinked and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research: ask the scientific question, identify the variable needed to answer it, conceive the best instrument to measure the variable, analyze the data, and ask the next question.

Space Science

The mission of NASA's Space Science Enterprise is to solve mysteries of the universe; explore the solar system; discover planets around other stars; search for life beyond Earth; chart the evolution of the universe; and understand its galaxies, stars, planets, and life. Within this enterprise, the Laboratory studies the evolution, composition, and dynamics of the atmospheres of other planets. We have flown instruments on the Atmosphere Explorers, Dynamics Explorer, Pioneer Venus Orbiter, and Galileo missions. These instruments have measured ion and neutral gas composition, neutral gas temperature and wind, and electron temperature and density.

Laboratory for Atmospheres scientists have completed work on two instruments flying on the Cassini mission. The Gas Chromatograph Mass Spectrometer (GCMS) will measure the chemical composition of gases and aerosols in the atmosphere of Titan. The Ion and Neutral Mass Spectrometer (INMS) will measure the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of Saturn's icy satellites.

Laboratory scientists have also completed work on a Neutral Mass Spectrometer (NMS) to measure the neutral atmosphere of Mars. That instrument is being flown on a joint mission with Japan called "*Nozomi*." *Nozomi* is scheduled to arrive at Mars in December 2003.

The Neutral Gas and Ion Mass Spectrometer (NGIMS) of the Comet Nucleus Tour (CONTOUR), is scheduled for launch in July 2002. It will measure the abundance and isotope ratios for many neutral and ion species in the coma of each comet during the flyby. These measurements, together with data from a dust experiment on this mission, will contribute to our understanding of the chemical composition of the nucleus itself and will allow us to study differences between the comets.

5. MAJOR ACTIVITIES

In the previous section, we provided a snapshot of the activities we pursue in the Laboratory for Atmospheres. Let's have a closer look. This section presents a more complete picture of our work in measurements, data sets, data analysis, and modeling. In addition, we'll discuss the Laboratory's support for the National Oceanic Atmospheric Administration's (NOAA) remote sensing requirements. Section 5 concludes with a listing of our project scientists, a description of our interactions with other scientific groups, and an overview of our efforts toward commercialization and technology transfer.

Measurements

Studies of the atmospheres of our solar system's planets–including our own–require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the ground. All instrument systems perform one or both of these functions:

- Providing information leading to a basic understanding of the relationship between atmospheric systems and processes
- Serving as calibration references for satellite instrument validation, or perform both functions

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Balloon and airborne platforms let us view such atmospheric processes as precipitation and cloud systems from a high-altitude vantage point but still within the atmosphere. Such platforms serve as a step in the development of spaceborne instruments.

Table II shows the principal instruments that have been built in the Laboratory or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table II also indicates each instrument's deployment— in space, on aircraft or balloons, or on the ground. Further information on each instrument appears on the pages following Table II. The four instruments that were completed under the Instrument Incubator Program (IIP) are identified by the IIP acronym.

Table II: Principal Instruments Supporting Scientific Disciplines in the Laboratory for Atmospheres

Space		Total Ozone Mapping Spectrometer (TOMS) – Earth Probe (EP) QuikTOMS Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE) – Shuttle Earth Polchromatic Imaging Camera (EPIC) – Triana	**IIP**: COmpact Vis IR (COVIR) – Shuttle	Gas Chromatograph Mass Spectrometer (GCMS) – Cassini Huygens Probe Ion and Neutral Mass Spectrometer (INMS) – Cassini Orbiter Neutral Mass Spectrometer (NMS) – *Nozomi* Neutral Gas and Ion Mass Spectrometer (NGIMS) – Comet Nucleus Tour (CONTOUR)
Aircraft	Large Aperture Scanning Airborne Lidar (LASAL) ER-2 Doppler Radar (EDOP) Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)	Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL) **IIP**: Raman Airborne Spectroscopic Lidar (RASL)	Cloud Physics Lidar (CPL) Leonardo Airborne Simulator (LAS) Cloud Radar System (CRS)	
Ground/ Laboratory	Scanning Raman Lidar (SRL) Goddard Lidar Observatory for Winds (GLOW) **IIP**: Lightweight Rain Radiometer	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Tropospheric Ozone Lidar **IIP**: Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) Aerosol and Temperature Lidar (AT Lidar)	Micro Pulse Lidar (MPL) cloud THickness from Offbeam Returns (THOR) Lidar Scanning Microwave Radiometer (SMiR) Surface Measurements for Atmospheric Radiative Transfer (SMART) The Sun-Sky-Surface photometer (3S)	

Spacecraft-Based Instruments (launch dates are in parentheses)

The ***Total Ozone Mapping Spectrometer (TOMS)*** on Earth Probe (EP) has provided daily mapping and long-term trend determination of total ozone, surface UV radiation, volcanic SO_2, and UV-absorbing aerosols (1996). For further information, contact Richard McPeters (Richard.D.McPeters.1@gsfc.nasa.gov).

The ***QuikTOMS*** Project will provide for continuity of the TOMS database beyond the TOMS-EP mission. A one-year overlap with TOMS-EP is desired for intercomparison of data and calibration (2001). For further information, contact Richard McPeters (Richard.D.McPeters.1@gsfc.nasa.gov).

The ***Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE)*** measured ozone profiles from the stratosphere down to the tropopause with high vertical resolution in 1997. SOLSE is a grating spectrometer that measured ozone in the upper stratosphere, while LORE is a filter radiometer that measured ozone in the lower stratosphere. The instruments are being reconfigured to more accurately simulate the performance expected from the Ozone Mapper and Profiler System (OMPS). A reflight is manifested on STS 107. This will be an important risk mitigation activity for the National Polar Orbiting Environmental Satellite System (NPOESS) ozone instrument (2001). For further information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

Earth Polychromatic Imaging Camera (EPIC) on Triana is a 10-channel spectroradiometer spanning the ultraviolet (UV) to the near-infrared (IR) wavelength range (317.5 to 905 nm). The main quantities measured are (1) column ozone, (2) aerosols (dust, smoke, volcanic ash, and sulfate pollution), (3) sulfur dioxide, (4) precipitable water, (5) cloud height, (6) cloud reflectivity, (7) cloud phase (ice or water), and (8) UV radiation at the Earth's surface. We will also measure other quantities related to vegetation, bi-directional reflectivity (hotspot analysis) and ocean color. EPIC has two unique characteristics: (1) EPIC takes the first spaceborne measurements from sunrise to sunset of the entire sunlit Earth and (2) EPIC performs the first simultaneous measurements in both the UV and visible wavelengths. These capabilities will allow us to determine diurnal variations and permit extended measurements of aerosol characteristics (2002). For further information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

COmpact Vis IR (COVIR) is an engineering model of an imaging radiometer for small satellite missions. The instrument is being developed under the Instrument Incubator Program (IIP) and will measure visible and IR wavelengths in the following ranges: 10.3-11.3 µm, 11.5-12.5 µm, 9.5-10.5 µm, and 0.67-0.68 µm. The system employs uncooled microbolometer focal plane detectors. The goal of COVIR is to enable future multi-sensor Earth-science missions to utilize smaller and lower-cost infrared and visible imaging radiometers. This will lead to improved cloud sensing through increased spatial resolution and coverage with spectral IR data. For further information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The ***Gas Chromatograph Mass Spectrometer (GCMS)*** for the Cassini Huygens Probe will measure the chemical composition of gases and aerosols in the atmosphere of Titan (1997), starting in 2004. For further information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The ***Ion and Neutral Mass Spectrometer (INMS)*** on Cassini Orbiter will determine the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of its icy satellites (1997), starting in 2004. For further information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The ***Neutral Mass Spectrometer (NMS)*** on the Japanese spacecraft *Nozomi* (Planet-B) will measure the composition of the neutral atmosphere of Mars to improve our knowledge and understanding of the energetics, dynamics, and evolution of the Martian atmosphere. The *Nozomi* spacecraft and mission were developed by the Japanese Institute of Space and Astronautical Science (1998). For further information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The ***Neutral Gas and Ion Mass Spectrometer (NGIMS)*** on the Comet Nucleus Tour (CONTOUR) mission will provide detailed compositional data on both gas and dust in the near-nucleus environment at precisions comparable to those of Giotto or better (2002). For further information, contact Paul Mahaffy (Paul.R.Mahaffy.1@gsfc.nasa.gov).

Aircraft-Based Instruments

The ***Large Aperture Scanning Airborne Lidar (LASAL)*** measures atmospheric backscatter with an emphasis on boundary-layer height and structure. Capable of (raster) scanning at up to 90 degrees per second, it provides a three-dimensional view of the aerosol structure of the lower troposphere and boundary layer. For further information, contact Stephen Palm (Stephen.P.Palm.1@gsfc.nasa.gov).

The ***ER-2 Doppler Radar (EDOP)*** measures vertical profiles of rain and winds within precipitation systems to improve our understanding of mesoscale structure of convective systems. The data are also used to validate spaceborne rain measurement algorithms. For further information, contact Gerald Heymsfield (Gerald.M.Heymsfield.1@gsfc.nasa.gov).

The ***Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)*** measures cloud and aerosol structure and dynamics via laser backscatter in three dimensions. Utilizing a unique conical scanning holographic telescope and a diode pumped solid state infrared laser, this compact high-performance lidar fits into low- to medium-altitude aircraft as well as in a portable ground-based environmental housing for relatively low cost field experiment deployments. HARLIE was successfully operated in two ground-based experiments last year to test and improve the technology and to develop a new data product: atmospheric wind profiles. The wind profiles were derived using time-lag correlation techniques on the structures of cloud and aerosol backscatter. HARLIE was also deployed to the ARM CART site in September–October 2000 where it provided video renderings of the atmospheric dynamic environment on a daily basis for nearly three weeks during the ARM Water Vapor Intensive Operating Period (IOP). The data from this campaign are being analyzed to provide ancillary wind profiles, boundary layer parameters, cloud statistics, and 1-micron backscatter profiles for the entire IOP. HARLIE has flown successfully on the NASA F-27 aircraft on engineering test flights. The next funded application is in an Army experiment in 2002 as a ground-based sensor to map dust plumes from troop activities at a major Army playground, tentatively Fort Bliss in El Paso, TX. This activity is part of EPA mandated studies in collaboration with investigators from Desert Research Institute. The size and weight and other technical aspects of the instrument, such as data products, are described on the HARLIE Web page: http://bll.gsfc.nasa.gov/harlie/. For further information contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

The GSFC ***Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL)*** is a two wavelength lidar system (308 nm and 355 nm) that detects two elastically scattered wavelengths and N_2-Raman scattered radiation at 332 nm and 387 nm. The system uses 20 data channels spread over the four detected wavelengths. The instrument was on board the DC-8 during the SOLVE campaign in the winter of 1999/2000. Colleagues at Langley contributed data channels for depolarization measurements at 532 nm and channels for aerosol backscatter at 1064 nm. Data

products are aerosol backscatter and vertical profiles of ozone and temperature. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Raman Airborne Spectroscopic Lidar (RASL)*** is currently being developed under NASA's Instrument Incubator Program (IIP) in collaboration with the Laboratory for Terrestrial Physics (David N. Whiteman, Code 924 is the PI). The instrument will address a large number of high priority atmospheric science measurement requirements, including water vapor, aerosol scattering, extinction, optical depth, depolarization, temperature, cloud liquid water amount and drop size, and cloud top and bottom heights. Through the use of a broadband spectrometer, full spectral tuning across the entire Raman band will also be possible, allowing us to attempt other experimental measurements such as cloud droplet temperature. RASL is on schedule for completion late in CY 2001. For further information contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

The ***Cloud Physics Lidar (CPL)*** measures cloud and aerosol structure from the high-altitude ER-2 aircraft, in combination with multispectral visible, microwave, and infrared imaging radiometers. The instrument operates at 1064, 532, and 355 nm wavelengths with a repetition rate of 5 kHz. The data are used in radiation and remote-sensing studies. For further information, contact Matthew McGill (Matthew.J.McGill.1@gsfc.nasa.gov).

The ***Leonardo Airborne Simulator (LAS)*** is an imaging spectrometer (hyperspectral) with moderate spectral resolutions. LAS will measure reflected solar radiation to retrieve atmospheric properties such as column water vapor amount, aerosol loadings, cloud properties, and surface characteristics. This instrument is currently under development and was successfully deployed in a series of SAFARI related campaigns in 1999-2000. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Cloud Radar System (CRS)*** is a 94 GHz millimeter-wave Doppler radar system for measuring cirrus clouds and precipitation with smaller reflectivities (smaller particles) than detectable with conventional rain radars. The system is designed for high-altitude ER-2 operation and operates at the same frequency as the CLOUDSAT radar. For further information, contact Gerald Heymsfield (Gerald.M.Heymsfield.1@gsfc.nasa.gov).

Ground-Based and Laboratory Instruments

The Scanning Raman Lidar (SRL) measures light scattered by water vapor, nitrogen, oxygen, and aerosols to determine the water vapor mixing ratio, aerosol backscattering, and aerosol extinction, as well as their structure in the troposphere. Measurements from this mobile system are important for studying radiative transfer, convection, and the hydrological cycle. They are also useful for assessing the water and aerosol measurement capabilities of surface-, aircraft-, and satellite-based instruments.

Using the SRL, a new technique was devised for measuring cloud liquid water, mean droplet radius and droplet number density. A new extension to the theory was developed that allows multiple scattering to be quantified. The technique is based on simultaneously measuring Raman and Mie scattering from cloud liquid droplets using the Raman lidar. The intensity of Raman scattering is known to be proportional to the amount of liquid present in cloud droplets. This fact is used as a constraint on calculated Mie intensity to calculate droplet radius and number density. The general relationship of retrieved average radius and number density is consistent with traditional cloud physics models.

A new technique for measuring cloud base altitude using SRL data was also developed. The technique has advantages over conventional elastic backscatter lidar measurements of cloud base during precipitating periods. A combination of the Raman-lidar-derived profiles of water-vapor-mixing ratio and aerosol-scattering ratio, together with the Raman-scattered signals from liquid drops, can minimize or even eliminate some of the problems associated with cloud-boundary detection using elastic lidars. The SRL was deployed to the ARM CART site in Billings, OK, during the ARM Water Vapor IOP in September and October. It was also used later in AFWEX, at the same location. A major objective of the Water Vapor IOP is to resolve discrepancies between various instruments measuring water vapor down to the 2% level. The SRL is a collaborative project with David N. Whiteman, Code 924. For further information, contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

The ***Goddard Lidar Observatory for Winds (GLOW)*** is a mobile Doppler lidar system that measures vertical profiles of wind from the surface to the stratosphere using the double-edge technique. The instrument operates at two wavelengths to measure winds using the laser energy backscattered from aerosols (wavelength=1064 nm) or molecules (wavelength=355 nm). The 1064 nm-channel data products are high spatial resolution wind profiles in the planetary boundary layer and lower troposphere and the 355 nm channel provides wind profiles to altitudes as high as 35 km. For further information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The small ***Lightweight Rain Radiometer*** is a Laboratory development under the Instrument Incubator Program (IIP). The radiometer will employ a thinned-array synthetic antenna at 10.7 GHz for future measurements from space. The instrument will provide global high-temporal-resolution precipitation measurements from a constellation of small satellites. For further information, contact Charles E. Cote (Charles.E.Cote.1@gsfc.nasa.gov).

The ***Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE)*** measures vertical profiles of ozone, aerosols, and temperature. The system collects elastically and Raman-scattered returns using DIfferential Absorption Lidar (DIAL). For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Tropospheric Ozone Lidar*** will measure tropospheric ozone at wavelengths that have a large ozone-absorption cross-section. The system will provide validation data for research and development programs aimed at monitoring tropospheric ozone from space. The system is in development to be completed in early 2001. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA)*** instrument is in development under the Instrument Incubator Program (IIP). The primary objective is high-resolution measurement of NO_2, SO_2, aerosol, and O_3. The core design is a wide field-of-view (FOV) front-end telescope that illuminates a filter/focal plane array (FFPA) package. For further information, contact Scott Janz (Scott.J.Janz.1@gsfc.nasa.gov).

The ***Aerosol and Temperature Lidar (AT Lidar)*** is a trailer-based instrument that makes measurements of vertical profiles of atmospheric aerosols and stratospheric temperature. Aerosol information is gathered at three wavelengths to provide particle size information. For further information, contact Thomas J. McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Micro Pulse Lidar (MPL)*** makes quantitative measurements of clouds and aerosols. MPL is a unique "eye-safe" lidar system that operates continuously (24 hours a day) in an autonomous fashion. Twenty instruments are currently deployed. In 2000, the MPL program was initiated for

continuous lidar monitoring at globally distributed sites. For further information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The cloud ***THickness from Offbeam Returns (THOR) Lidar*** will determine the physical and optical thickness of dense cloud layers from the cloud Green's function, which is the halo of diffuse light up to 0.5 km from the entry point of a lidar beam incident on the cloud layer. Lidar returns at these wide angles are stronger for thicker clouds and are relatively insensitive to cloud microphysics. For further information, contact Robert Cahalan (Robert.F.Cahalan.1@gsfc.nasa.gov).

The ***Scanning Microwave Radiometer (SMiR)*** will measure the column amounts of water vapor and cloud liquid water using discrete microwave frequencies. This instrument was successfully deployed in a series of SAFARI related campaigns in 1999-2000. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Surface Measurements for Atmospheric Radiative Transfer (SMART)*** is a suite of surface remote-sensing instruments developed and mobilized to collocate with satellite overpass at targeted areas for retrieving physical/radiative properties of the Earth's atmosphere and for characterizing surface properties. The SMART includes many broadband radiometers, shadow-band radiometers, sun photometers, solar spectrometers, a whole-sky camera, a micro-pulse lidar, and a microwave radiometer, as well as meteorological probes for atmospheric pressure, temperature, humidity, and wind speed/direction. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Sun-Sky-Surface photometer (3S)*** fabrication was funded through GSFC/DDF, with the collaboration of Biophysics Branch (Code 923) and Detector System Branch (Code 553). The 3S contains 14 discrete channels, ranging from the ultraviolet to shortwave-infrared spectral region, and scans the upper (atmosphere) and lower (surface) hemispheres during its operation. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

Field Campaigns

Field campaigns typically use the resources of NASA, other agencies, and other countries to carry out scientific experiments or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2 and DC-8, serve as platforms from which remote-sensing and *in situ* observations are made. Ground systems are also used for soundings, remote sensing and other radiometric measurements. In 2000, Laboratory personnel supported many such activities as scientific investigators, or as mission participants, in the planning and coordination phases. Field campaigns supported in this way include the following:

The ***Atmospheric Radiation Measurement Program (ARM)*** is a Department of Energy program in which NASA participates. ARM focuses on obtaining field measurements and developing models to better understand the processes that control solar and thermal infrared radiative transfer in the atmosphere, especially in clouds and at the Earth's surface. The goal is to improve the tools used to study global climate change; i.e., General Circulation Models (GCM). Laboratory personnel participate in various aspects of this program, especially the intensive observation periods (IOPs) such as the WISC-T2000 ER-2 EOS Terra validation mission that was coordinated with the Spring 2000 Cloud IOP (CLS), and the Fall 2000 Water Vapor IOP (SRL, HARLIE). For further information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The ***GroundWinds Validation Campaign*** was carried out to validate the performance of ground-based Doppler lidar techniques and to demonstrate the technology used by the University of New Hampshire GroundWinds Doppler Lidar. The experiment was held at the GroundWinds facility

in North Conway, NH, and included several active Doppler systems, all simultaneously measuring wind profiles. Regular rawinsonde balloon observations provided further corroborative data. The Goddard Lidar Observatory for Winds (GLOW) provided molecular motion observations in the upper troposphere for comparison with the UNH GroundWinds lidar. In addition to GLOW, NOAA provided a radar profiler and a coherent Doppler lidar measuring aerosol motion in the boundary layer and lower troposphere. The combination of all these data, taken under a variety of atmospheric conditions, will aid in the evaluation of the readiness of Doppler lidar technology to meet NOAA and NASA requirements for space-based wind profiles observations. For further information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The ***Network for the Detection of Stratospheric Change (NDSC)*** is an international program to determine changes in the physical and chemical state of the stratosphere, to obtain data to test and improve multidimensional stratospheric chemical and dynamical models, and to provide independent calibration of satellite instruments. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

Stratospheric Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation Experiment (SOLVE) is a measurement campaign designed to examine the processes controlling ozone levels at mid- to-high latitudes. During the winter of 1999-2000, this NASA-sponsored experiment was jointly conducted with the European Commission-sponsored Third European Stratospheric Experiment on Ozone (THESEO 2000). Direct observations using the NASA ER-2 and DC-8 aircraft have confirmed that polar stratospheric clouds (PSCs) are key components of the ozone loss process. Further, we now understand how these cloud particles modify the stratosphere as they slowly fall. Such information will be applied in both diagnostic and assessment models for more accurate predictions of changes of stratospheric ozone. For further information, contact Paul A. Newman (Paul.A.Newman.1@gsfc.nasa.gov).

The ***Southern Africa Fire-Atmosphere Research Initiative (SAFARI)*** focused on biomass burning in the Savannah region of southern Africa. SAFARI is a critical part of EOS Terra (MODIS, MOPITT, MISR, CERES, and ASTER) science and validation mission in collaboration with international research communities. Opportunities to study Namibian marine stratus clouds at the end of SAFARI-2000 were also taken. This marked one of the most aggressive and successful coupled ground-based, *in situ*, and remote sensing campaigns ever in Africa. Our key objectives were to understand the linkages between land-atmosphere processes and to understand the relationship of biogenic, pyrogenic, or anthropogenic emissions and the consequences of their deposition to the biogeophysical and biogeochemical systems of southern Africa.

This campaign involved two aircraft and an array of instruments. Both the NASA ER-2 aircraft and the University of Washington CV-580 participated in SAFARI. Primary instruments of interest for the ER-2 are the MAS, MOPITT-A, AirMISR, SSFR, LAS, S-HIS (these simulating Terra instruments), and CPL (a lidar for profiling the atmosphere). The ER-2 coordinated with *in situ* aerosol, radiation, and chemistry measurements on the CV-580 and overflew numerous AERONET locations in Namibia, Botswana, South Africa, Zambia, and Zimbabwe and over the SAVE/SMART site in Skukuza, South Africa. The Cloud Physics Lidar (CPL) on the NASA ER-2 performed well in its first field mission during the SAFARI experiment. The CPL replaced the former CLS and the advances permitted enhanced science capabilities and facilitated more rapid data processing. The initial flights showed heavy aerosol loading capped by strong inversions. Ground-based MPL instruments were installed and worked well in Mongu, Zambia and Skukuza, South Africa.

These ground sites were part of the SAFARI campaign. They provided monitoring of the elevated structure of smoke and haze. The sites also served as ground truth sources for the NASA ER-2 aircraft remote sensing. The Skukuza site will likely become a permanent site for the MPL network project, which is to involve over a dozen globally distributed sites for aerosol and cloud-structure measurements as needed for climate and satellite verification studies.

For more information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov). For more information about SMART, contact Matthew McGill (Matthew.J.McGill.1@gsfc.nasa.gov). For more information about CPL, contact Elsworth Welton (Elsworth.J.Welton.1@gsfc.nasa.gov).

The ***Puerto Rico Dust Experiment (PRiDE, June 2000)*** was designed to measure the properties of Saharan dust transported across the Atlantic Ocean to the Caribbean and is a NASA collaborative endeavor with the Office of Naval Research and the University of Miami. In the summer months, moderate quantities of desert dust are observed in the Caribbean. Puerto Rico is the first significant landfall for the dust travelling across the ocean from Africa. The experiment took place June–July 2000. During PRiDE, simultaneous aerosol optical thickness, precipitable water vapor, and downwelling irradiance measurements were made from the SMART and a low-flying aircraft at the time of the Terra/MODIS overpass. Analyses of PRiDE measurements will lead us to a better understanding of dust optical, microphysical, and chemical properties, especially the significant parameters of dust single scattering albedo and nonsphericity. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The International Global Atmospheric Chemistry program has organized a series of ***Aerosol Characterization Experiments (ACE-Asia)*** to acquire data sets needed for assessing aerosol effects in major regions of the globe. ACE-Asia is designed to study the compelling variability in spatial and temporal scales of both pollution-derived and naturally occurring aerosols. These aerosols often exist in high concentrations over eastern Asia and along the rim of the western Pacific. Phase-I of ACE-Asia will be conducted from March –May 2001 in the vicinity of the Gobi desert, the east coast of China, the Yellow Sea, and Japan, along the pathway of Kosa (severe events that blanket east Asia with yellow desert dust, peaking in spring). For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Boundary Layer Dynamics Lidar*** group organized a joint field experiment to study the interaction between gravity waves and active marine boundary layer convection induced by cold air outbreaks off the Atlantic Coast during late fall and winter months, when the air-sea temperature differences are greatest. These episodes often lead to the development of cloud streets, long parallel linear features in the clouds in the first few days following the cold frontal passage. The mechanism for the formation of these features has been a matter of some debate with boundary-layer meteorologists. Are they caused by alternating helical roles within the boundary layer? Or are they merely organizing themselves under the crests of gravity waves induced by shear at the top of the marine boundary layer? Are the structures present in the pre-cloud environment? Is significant momentum transfer taking place as a result of any gravity wave activity under these conditions? Assembling atmospheric remote-sensing instrument experimenters and boundary layer theoreticians from several universities in the U. S. and Europe, we hope to answer these and other questions with airborne measurements in a field experiment dubbed Convective Wave Experiment (COWEX). For further information, contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

Data Sets

In the previous discussion, we examined the array of instruments we use to gather weather and climate data. Once we have obtained the raw data from these instruments, we arrange the information into data sets useful for studying various atmospheric phenomena.

Televised Infrared Operational Satellite (TIROS) Operational Vertical Sounder Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multi-year climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is the TIROS Operational Vertical Sounder (TOVS). TOVS is comprised of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 to the present, using an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979-2000 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount and cloud height, OLR and clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, NOAA 6,7,8,9,10,11,12, and 14. Equivalent future data sets will be produced from NOAA 15 and 16 ATOVS data and from AIRS data on EOS Aqua. We have demonstrated that TOVS data can be used to study interannual variability of surface and atmospheric temperatures and humidity, cloudiness, OLR, and precipitation. We have developed the 21-year TOVS Pathfinder Path A data set. We are developing improved methodologies to analyze ATOVS data to produce a future climate data set and also to use in conjunction with the DAO data assimilation system to improve analyses and numerical weather prediction skill. We have also developed the methodology to be used by the AIRS science team to generate products from AIRS for weather and climate studies. In joint work with the DAO, the AIRS sounding products will be assimilated into the DAO GEOS 3 system to demonstrate how well the AIRS data will improve weather prediction skill. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

Tropospheric Ozone Data

Gridded data sets on tropospheric column ozone (TCO) and stratospheric column ozone (SCO) in the tropics for 1979-present are now available from NASA Goddard Space Flight Center via either direct ftp, World Wide Web, or electronic mail. Until recently, the primary method to derive TCO and SCO from satellite data was by combining TOMS and SAGE ozone measurements. At NASA Goddard, monthly averaged TCO and SCO data are derived in the tropics for January 1979–present using the convective cloud differential (CCD) method [Ziemke et al., J. Geophys. Res.,103, 22115-22127, 1998]. Further details regarding methodology and new adjustments made for aerosol contamination are discussed in Ziemke et al. [Bull. Amer. Meteorol. Soc., 81,580-583, 2000]. These data have recently been used in several published studies within Code 916 to characterize tropospheric ozone variabilities from monthly to decadal time scales. The CCD, TCO, and SCO data may be obtained via World Wide Web (http://hyperion.gsfc.nasa.gov/Data_services/Data.html). For more information, contact Sushil Chandra (Sushil.Chandra.1@gsfc.nasa.gov).

Aerosol Products from the Total Ozone Mapping Spectrometer

Laboratory scientists are generating a unique new data set of atmospheric aerosols by reanalyzing the 17-year data record of Earth's ultraviolet albedo as measured by the TOMS. Since 1996, Laboratory staff have developed techniques for extracting aerosol information from measured UV

radiances. The UV technique differs from conventional visible methods in that the UV measurements can reliably separate UV absorbing aerosols (such as desert dust and smoke from biomass burning) from non-absorbing aerosols (such as sulfates, sea-salt, and ground-level fog). In addition, the UV technique can measure aerosols over land and can detect all types of aerosols over snow/ice and clouds.

TOMS aerosol data are currently available in the form of a contrast index (and now as optical depth). The index provides excellent information about sources, transport, and seasonal variation of a variety of aerosol types. Work is currently in progress to release the data relating the index to aerosol optical thickness and single-scatter albedo. For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

Multiyear Global Surface Wind Velocity Data Set

The Special Sensor Microwave Imagers (SSM/I) aboard three Defense Meteorological Satellite Program (DMSP) satellites have provided a large data set of surface wind speeds over the global oceans from July 1987 to the present. These data are characterized by high resolution, coverage, and accuracy, but their application has been limited by the lack of directional information. In an effort to extend the applicability of these data, the DAO developed methodology to assign directions to the SSM/I wind speeds and to produce analyses using these data. This methodology has been used to generate a 12.5-year data set (from July 1987 through December 1999) of global SSM/I wind vectors. These data are currently being used in a variety of atmospheric and oceanic applications and are available to interested investigators. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Global Precipitation Data Set

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing intra- and inter-annual climatic fluctuations on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory have led the GPCP effort to merge microwave data from low-Earth-orbit satellites, infrared data from geostationary satellites, and data from ground-based rain gauges to produce the best estimates of global precipitation.

Version 2 of the GPCP merged data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at World Data Center A (located at the National Climatic Data Center in Asheville, NC), at the Goddard Distributed Active Archive Center (DAAC), and at the Global Precipitation Climatology Centre (located at the Deutscher Wetterdienst in Offenbach, Germany). Evaluation is ongoing for this long-term data set in the context of climatology, ENSO-related variations and trends, and comparison with the new TRMM observation. Development of data sets with finer time resolution (daily and 3-hr) is proceeding. A daily, global analysis for the period 1997-present has also been completed for the GPCP and is available from the archives. A 3-hr resolution rainfall analysis combining TRMM and other satellite data is being developed and is currently being tested. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

SHADOZ (Southern Hemisphere ADditional OZonesondes) Data Set

The first-archived data set dedicated to tropical and sub-tropical ozonesonde profiles is coordinated in Code 916 within the Laboratory. Initiated three years ago in a unique effort to fill in gaps in the tropical ozone profile record, SHADOZ (Southern Hemisphere ADditional OZonesondes) meets community needs for development of ozone-retrieval satellite algorithms, validation of new ozone products, global chemical-transport model evaluation and for basic understanding of ozone in the tropics [Thompson et al., 2000]. With weekly ozonesonde launches at ten tropical stations, and occasional tropical field campaigns, SHADOZ has supplied high-quality ozone and temperature profiles to ~35 km and relative humidity to 12 km, since 1998. In less than 3 years, over 900 profiles have been added to the world's ozone data record. Thompson, A M., J. C. Witte, F. J. Schmidlin, S. J. Oltmans, R. D. McPeters, "SHADOZ (Southern Hemisphere ADditional OZonesondes): An Ozonesonde Network for Satellite Validation, Climatology and Modeling, " Extended Abstract Volume, 32nd Quadrennial Ozone Symposium, Sapporo, Japan, NASDA, Tokyo, 3-8 July 2000. For more information, contact Anne Thompson, (Anne.M.Thompson.1@gsfc.nasa.gov).

Multiyear Data Set of Satellite-based Global Ocean Surface Turbulent Fluxes

The fluxes of momentum (or wind stress), latent heat (due to evaporation), and sensible heat, called turbulent fluxes, at the global ocean surface are essential to weather, climate, and ocean problems. These fluxes are required for driving ocean models and validating coupled ocean-atmosphere global models, as well as performing climate studies. The Special Sensor Microwave/Imagers (SSM/I) aboard three Defense Meteorological Satellite Program (DMSP) satellites have provided near-global coverage with improved coverage, spatial resolution, and accuracy over prior passive microwave instruments. Laboratory scientists have developed methodology to produce the Version 1 data set of Goddard Satellite-Based Surface Turbulent Fluxes (GSSTF) from the SSM/I radiances and other data. It provides daily- and monthly-mean turbulent fluxes and some relevant parameters over global oceans for the period July 1987-December 1994 and the 1988-1994 annual- and monthly-mean climatologies of the same variables. These variables are wind stress, latent heat flux, sensible heat flux, 10-m wind speed, 10-m specific humidity, sea-air humidity difference, and lowest 500-m bottom-layer precipitable water. Its resolution is $2.0^{\circ} \times 2.5^{\circ}$ lat-long. The data set is archived at the Goddard Distributed Active Archive Center (DAAC) and participates in the SEAFLUX Ocean Surface Turbulent Flux Project for comparison with other flux data sets. For more information, contact Shu-Hsien Chou (Shu-Hsien.Chou.1@gsfc.nasa.gov).

Data Analysis

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA major responsibility for studying the ozone layer.

Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, and human-made pollutants,

such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

An emerging area of research is to understand the transport of chemically active trace gases across the tropopause boundary. It has been suggested that changes in atmospheric circulation caused by greenhouse warming may affect this transport and, thus, delay the anticipated recovery of the ozone layer in response to phase-out of CFCs. For more information, contact Paul A. Newman (Paul.A.Newman.1@gsfc.nasa.gov).

Total Column Ozone and Vertical Profile

Laboratory for Atmospheres scientists have been involved in measuring ozone since the late 1960s when a satellite instrument, the Backscatter Ultraviolet (BUV) Spectrometer, was launched on NASA's Nimbus4 satellite to measure the column amount and vertical distribution of ozone. These measurements are continuing aboard several follow-on missions launched by NASA, NOAA, and, more recently, by the ESA.

An important activity in the Laboratory is developing a high-quality, long-term ozone record from these satellite sensors and comparing that record with ground-based and other satellite sensors. This effort, already more than a quarter century in duration, has produced ozone data sets that have played a key role in identifying the global loss of ozone due to certain human-made chemicals. This knowledge has contributed to international agreements to phase out these chemicals by the end of this century. For more information, contact Pawan K. Bhartia (Pawan.K.Bhartia.1@gsfc.nasa.gov).

Surface UV Flux

The primary reason for measuring atmospheric ozone is to understand how the UV flux at the surface might be changing and how this change might affect the biosphere. The sensitivity of the surface UV flux to ozone changes is calculated using atmospheric models and the measured values of ozone, aerosol, and cloud amounts. Yet, until recently, we had no rigorous test of these models, particularly in the presence of aerosols and clouds. By comparing a multi-year data set of surface UV flux generated from TOMS data and high-quality ground-based measurements, we are increasingly able to quantify the respective roles of ozone, aerosols, and clouds in controlling the surface UV flux over the globe. While the agreement between satellite and ground-based measurements of surface UB flux is becoming good, the satellite data covers regions not normally accessible by the ground-based instruments (e.g., oceans, deserts, etc.). For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

Data Assimilation

The DAO in the Laboratory has taken on the challenge of providing to the research community a coherent, global, near-real-time picture of the evolving Earth system. The DAO is developing a state-of-the-art Data Assimilation System (DAS) to extract the usable information available from a vast number of observations of the Earth system's many components, including the atmosphere, the oceans, the Earth's land surfaces, the biosphere, and the cryosphere (ice sheets over land or sea).

The DAS is made of several components including an atmospheric prediction model, a variational physical space analysis scheme, and models to diagnose unobservable quantities. Each of these components requires intense research, development, and testing. Much attention must be given to insuring that the components interact properly with one another to produce meaningful,

research-quality data sets for the Earth-system-science research community. (See later section on Modeling). For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Observing System Simulation Experiments

Since the advent of meteorological satellites in the 1960s, considerable research effort has been directed toward designing space-borne meteorological sensors, developing optimum methods for using satellite soundings and winds, and assessing the influence of satellite data on weather prediction. Observing system simulation experiments (OSSE) have played an important role in this research. Such studies have helped in designing the global observing system, testing different methods of assimilating satellite data, and assessing the potential impact of satellite data on weather forecasting.

At the present time, OSSEs are being conducted to (1) provide a quantitative assessment of the potential impact of currently proposed space-based observing systems on global change research, (2) evaluate new methodology for assimilating specific observing systems, and (3) evaluate tradeoffs in the design and configuration of these observing systems. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Seasonal-to-Interannual Variability and Prediction

Climate research seeks to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote-sensing data, historical climate data, model outputs, and assimilated data. Climate diagnostic studies will be combined with modeling studies to unravel physical processes underpinning seasonal-to-interannual variability. The key areas of research include the El Niño Southern Oscillation (ENSO), monsoon variability, interseasonal oscillation, and water vapor and cloud feedback processes. Several advanced analytical techniques are used, including wavelets, multivariate empirical orthogonal functions, singular value decomposition, and nonlinear system analysis.

The Laboratory is also involved in NASA's Seasonal-to-Interannual Prediction Project (NSIPP). This collaboration between NASA and outside scientists is developing a system to predict El Niño events by utilizing a combination of satellite and *in situ* data. NSIPP will also employ a high-resolution atmosphere-land data assimilation system that will capitalize on the host of new high-resolution satellite data. This capability will allow us to better characterize the local and remote physical processes that control regional climates and limit predictability.

Promoting the use of satellite data is a top priority. Important satellite-derived data sets include TOPEX/Poseidon and Jason-1 ocean topography, the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), SSM/I, QuikSCAT, MSU, and TOVS Pathfinder data. Data from TRMM and EOS Terra and EOS Aqua platforms will be used extensively, as they become available. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Rain Measurements

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the Advanced Microwave Scanning Radiometer (AMSR) on EOS Aqua.

The retrieval techniques include the following: (1) A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations. (2) An empirical relationship that relates cloud thickness and other parameters to rain rates, using TOVS sounding retrievals. (3) An analysis technique that uses low-orbit microwave, geosynchronous infrared, and rain gauge information to provide a merged, global precipitation analysis. The merged analysis technique is now being used to produce global daily and tropical 3-hourly analyses.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, the climatological contribution of tropical cyclone rainfall, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

Rain Measurement Validation for the TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites world wide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the Goddard DAAC. With these products, the validity of TRMM measurements will be established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

Predicting Errors in Satellite Rainfall Measurements

To use TRMM maps of monthly rainfall, we need some measure of the accuracy of the satellite average. We have developed a statistical model of rain behavior that predicts that the random error in satellite rainfall averages—not including systematic biases that might be present—should depend in a straightforward way on the local average rain amounts and simple measures of rain variability. We have seen behavior consistent with the prediction in a number of studies based on simulations using rain gauges and radar data. The model prediction has recently been confirmed using rain observations from the Defense Meteorological Satellite Program satellites. Based on the model, we are developing a simple method of estimating the error levels in satellite rainfall so that satellite rain products can be accompanied by documented estimates of intrinsic error in the averages provided. [T.L. Bell, P.K. Kundu, and C.D. Kummerow, to appear in *J. Appl. Meteorology*.] For more information, contact Thomas L. Bell (Thomas.L.Bell.1@gsfc.nasa.gov).

Aerosols/Cloud Climate Interactions

Theoretical and observational studies are being carried out to analyze the optical properties of aerosols and their effectiveness as cloud condensation nuclei. These nuclei produce different drop size distributions in clouds, which, in turn, will affect the radiative balance of the atmosphere.

We developed algorithms to routinely derive aerosol loading, aerosol optical properties, and total precipitable water vapor data products from the EOS-Terra Moderate Resolution Imaging Spectroradiometer (MODIS). These algorithms are being evaluated, modified, and verified using the global MODIS data and information from the Aerosol Robotic Network (AERONET) of sun/sky radiometers. MODIS and AERONET data are being used to evaluate the global

distribution of aerosols, their properties, and their radiative forcing of climate. For more information, contact Yoram Kaufman (Yoram.J.Kaufman.1@gsfc.nasa.gov).

Laboratory scientists are actively involved in analyzing data recently obtained from national and international campaigns. These campaigns include the Puerto Rico Dust Experiment (PRiDE) and the Southern Africa Fire-Atmosphere Research Initiative, (SAFARI) 2000. For more information, contact Lorraine Remer (Lorraine.A.Remer.1@gsfc.nasa.gov).

Hydrologic Processes and Radiation Studies

Laboratory scientists are developing methods to estimate atmospheric water and energy budgets. These methods include calculating the radiative effects of absorption, emission, and scattering by clouds, water vapor, aerosols, CO_2, and other trace gases. The observational data include the ERBE radiation budgets, ISCCP clouds data, Geostationary Meteorological Satellite (GMS; Japan) radiances, National Center for Environmental Prediction (NCEP) sea surface temperature, and Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) observations. The models include the Goddard Earth Observing System (GEOS) GCM, the Goddard Cloud Ensemble model (GCE), and an ocean mixed layer model.

Laboratory scientists study the response of radiation budgets to changes in water vapor and clouds during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. We also investigate the relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature. In addition, we assess the impacts of basin-scale sea surface temperature fluctuations such as the El Niño on regional climate variability over the Indo-Pacific region, North America, and South America. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Earth Observing System Interdisciplinary Investigations

The overall goal of NASA's EOS Program is to determine the extent, causes, and regional consequences of global climate change. This major scientific challenge will be addressed by more than 20 instruments flown on a series of spacecraft over a period of at least 15 years. In addition to the scientific investigations to be carried out by the instrument scientists, the EOS program also supports various interdisciplinary science investigations. Interdisciplinary investigations, such as the two described below, are designed to improve understanding of the Earth as a system by developing and refining integrated models that will use observations from EOS instruments.

Stratospheric Chemistry and Dynamics

The goal of Laboratory investigations of stratospheric chemistry and dynamics is to separate natural from human-made changes in the Earth's atmosphere, to determine their effects on ozone, and to assess radiative and dynamical feedbacks. We do this by analyzing stratospheric chemical and dynamical observations from current satellites and from aircraft campaigns. Studies include examining the processes that produce the Antarctic ozone hole and understanding similar processes that are occurring in the northern polar regions. The investigation combines Upper Atmosphere Research Satellite (UARS) data, trajectory modeling, and TOMS observations. This work will continue as new instruments are deployed on aircraft and satellites by the United States and by other nations. For more information, contact Mark Schoeberl (Mark.R.Schoeberl.1@gsfc.nasa.gov).

Regional Land-Atmosphere Climate Simulation System (RELACS)

An end-to-end RELACS system is being developed in the Laboratory. RELACS consists of four components: A nested mesoscale model (MM5), a coupled land surface model, a regional four-dimensional data assimilation (4DDA) component, and a general circulation component. The

investigation will provide downscaling of large-scale climate forcings derived from GCM and from 4DDA.

The core component of RELACS is a MM5 derived from the National Center for Atmospheric Research (NCAR)/Pennsylvania State University.

The MM5 is a non-hydrostatic meso-alpha- (200-2000km) and meso-beta- (20-200 km) scale primitive equation model. MM5 is an excellent tool for studying the multi-scale dynamics associated with precipitation processes and their impact on regional hydrological cycles. Improved physics include microphysical processes, radiation, land-soil-vegetation, and ocean mixed-layer processes. These variables have been incorporated to produce realistic simulations of tropical-midlatitude precipitation systems and their relationship to the large-scale environment. Components of the physical package have been tested for various mesoscale convective systems, including monsoon depressions, supercloud clusters, and meso-scale convective complexes. In an effort to develop RELACS, the MM5 has been coupled with the Land Surface Model (LSM), the Parameterization for Land Atmosphere Cloud Exchange (PLACE) model. The MM5-LSM will be nested within the GEOS GCM over continental scale regions in Southeast Asia and in the continental United States.

This approach represents a new Laboratory effort geared toward regional water cycle and climate studies, with emphasis on regional climate and water resource assessment under the Earth Science strategic plan and the science priorities of the US Global Change Research Program (USGCRP). For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Modeling

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, we must couple the atmospheric GCM with ocean and land-surface models. Much of the work in this area is conducted in collaboration with Goddard's Laboratory for Hydrospheric Processes, Code 970. The ocean models predict the global ocean circulation including the sea surface temperature (SST)–when forced with atmospheric heat fluxes and wind stresses at the sea surface. Land-surface models are detailed representations of the primary hydrological processes, including evaporation; transpiration through plants; infiltration; runoff; accumulation, sublimation, and melt of snow and ice; and groundwater budgets.

One of the main objectives of coupled models is forecasting seasonal-to-interannual anomalies such as the El Niño phenomenon. Laboratory scientists are involved in NSIPP, which was established in Goddard's Laboratory for Hydrospheric Processes. NSIPP's main goal is to develop a system capable of assimilating hydrologic data and using that data with complex, coupled ocean-atmosphere models to predict tropical SST with lead times of 6–14 months. A second goal is to use the predicted SST in conjunction with coupled atmosphere-land models to predict changes in global weather patterns. For more information, contact Max Suarez (Max.J.Suarez.1@gsfc.nasa.gov).

Global Modeling and Data Assimilation

Development of the Data Assimilation System

The DAO currently uses the GEOS-3 DAS to support the EOS Terra Mission. The GEOS-3 DAS is a major upgrade of the GEOS-1 DAS used for the first NASA reanalysis. The GEOS-3 DAS provides data products at a higher horizontal resolution (1° longitude by 1° latitude) and employs

a new Physical-space Statistical Analysis System (PSAS). Other improvements include an interactive Mosaic-based land surface model, a state-of-the-art moist turbulence scheme, an on-line estimation and correction procedure for systematic forecast errors, and assimilation of space-borne observations of marine surface winds and total precipitable water. In the next upgrade scheduled before the EOS Aqua launch, the GEOS-3 DAS will be capable of assimilating interactively retrieved TOVS and advanced sounder data and precipitation data from TRMM and SSM/I instruments.

For the EOS-Aqua and beyond, the DAO is developing a next-generation numerical model for climate prediction and data assimilation in collaboration with NCAR. In addition, DAO is developing advanced data assimilation techniques using a combination of Kalman filtering and four-dimensional variational approaches. These techniques will allow us to make better use of synoptic observations. DAO is also developing flow-dependent covariance models to maximize the benefit of high spatial resolution of the observations and of the model. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Development of the Next-Generation Global Model

The DAO is collaborating with the NCAR to develop a unified global general circulation model for climate, numerical weather prediction, data assimilation, and chemical constituent transport applications. The prototype configuration consists of a finite-volume, flux-form semi-Lagrangian dynamic core developed at the DAO, and physical parameterizations and land surface schemes available through NCAR. The DAO dynamic core, which is a candidate for incorporation into the NCAR Community Climate Model version 4 (CCM4), is highly accurate in conservation properties; it also eliminates several known deficiencies of the spectral representation of the dynamic core. For more information, contact Shian-Jiann Lin (Shian-Jiann.Lin.1@gsfc.nasa.gov).

Cloud and Mesoscale Modeling

The mesoscale (MM5) and cloud-resolving Goddard Cumulus Ensemble (GCE) models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones and frontal rainbands, tropical and midlatitude deep convective systems, surface (ocean and land; i.e., vegetation and soil) effects on atmospheric convection, cloud-chemistry interactions, and stratospheric-tropospheric interaction. Other important applications include assessment of the potential benefits of assimilating satellite-derived water vapor, winds and precipitation fields on tropical and extra-tropical regional-scale (i.e., hurricanes and cyclones) weather simulations, and climate applications. The latter involve long-term integration of the models and allow the study of air-sea and cloud-radiation interactions and their role in cloud-radiation climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy and radiative exchange processes, and diabatic heating and water budgets associated with tropical and mid-latitude weather systems.

Data collected during several major field programs, TOGA COARE (1992-1993), SCSMEX (1998), TRMM LBA (1999), and TRMM KWAJEX (1999), was used to validate the GCE model. The MM5 was improved in order to study regional climate variation.

The models also are used to develop retrieval algorithms. For example, the GCE model is providing TRMM investigators with four-dimensional data sets for developing and improving TRMM rainfall and latent heating retrieval algorithms. Four-dimensional latent heating structures (5° by 5°, monthly) were retrieved from December 1997 to August 2000. For more information, contact Wei-Kuo Tao (Wei-Kuo.Tao.1@gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of physical sub-models of the climate system is an integral part of climate modeling activity. Laboratory scientists are actively involved in developing and improving physical parameterizations of the major radiative transfer and moisture processes in the atmosphere. Both of these areas are extremely important for eliminating model biases and leading to a better understanding of the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

For atmospheric hydrologic processes, we are evaluating and improving a prognostic cloud liquid water scheme, which includes representation of source and sink terms as well as horizontal and vertical advection of cloud material. This scheme incorporates attributes from physically based cloud life cycles, including the effects of downdraft, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity correction. We are evaluating coupled radiation and the prognostic water schemes with *in situ* observations from the ARM and TOGA-COARE IOPs as well as satellite data. For land-surface processes, a new snow physics package is being evaluated with GWEX GSWP data sets. It is currently in the GEOS GCMs. Moreover, the soil moisture prediction is extended down to 5m, which often goes through the groundwater table. All these improvements are found to better represent the hydrologic cycle in a climate simulation. For more information, contact Yogesh Sud (Yogesh.C.Sud.1@gsfc.nasa.gov).

Trace Gas Modeling

We have developed two- and three-dimensional models to understand the behavior of ozone and other atmospheric constituents. We use the two-dimensional models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects, such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. The three-dimensional models simulate the evolution of ozone and trace gases that affect ozone. The constituent transport is calculated utilizing meteorological fields (winds and temperatures) generated by the DAO. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and interannual. The model simulations are compared with observations, with the goal of improving our understanding of the complex chemical and dynamical processes that control the ozone layer.

The modeling effort has evolved in four directions: (1) *Lagrangian models* are used to calculate the chemical evolution of an air parcel along trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations. (2) *Two-dimensional (2D) non-interactive models* have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multidecadal chemical assessment studies. (3) *Two-dimensional interactive models* include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes. (4) *Three-dimensional (3D) models* have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport.

We use trace gas data from sensors on the UARS, on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model

processes. The integrated effects of processes such as stratosphere troposphere exchange, not resolved in 2D and 3D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass.1@gsfc.nasa.gov).

Support for National Oceanic and Atmospheric Administration Operational Satellites

In the preceding pages, we examined The Laboratory for Atmosphere's work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists assure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Post-doctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

Laboratory members are actively involved in the NPOESS Internal Government Studies (IGS) and support the Integrated Program Office (IPO) Joint Agency Requirements Group (JARG) activities.

Geostationary Operational Environmental Satellites

NASA GSFC project engineering and scientific personnel support NOAA for the GOES operational satellites. GOES supplies images and soundings to study atmospheric processes, such as moisture, winds, clouds, and surface conditions. In particular, GOES observations are used by climate analysts to monitor the diurnal variability of clouds and rainfall and to track the movement of water vapor in the upper troposphere. In addition to high quality imagery, the GOES satellites also carry an infrared multichannel radiometer that NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States. These mesoscale soundings are improving NOAA's numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images for regions all over the western hemisphere via the World Wide Web (http://rsd.gsfc.nasa.gov/goes/). For more information, contact Dennis Chesters (Dennis.Chesters.1@gsfc.nasa.gov).

Polar Orbiting Environmental Satellites

Algorithms are being developed and optimized for the HIRS-3 and the Advanced Microwave Sounding Unit (AMSU) first launched on NOAA 15 in 1998. Near real-time analysis will be carried out thereafter, as was done with HIRS2/MSU data. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

Solar Backscatter Ultraviolet/2

NASA has the responsibility to determine and monitor the pre-launch and post-launch calibration of the SBUV/2 instruments that are included in the payload of the NOAA polar-orbiting satellites. We further have the responsibility to continue the development of new algorithms to determine more accurately the concentration of ozone in the atmosphere.

We have recently applied an upgraded version 7 algorithm for the total column ozone product being produced from the SBUV/2 data. The algorithm is similar to that now being used to produce TOMS data. It goes further than the TOMS algorithm because the SBUV/2 has extra.

shorter wavelengths designed for determination of the profile of concentration of ozone with altitude. One of these wavelengths, 305.6 nm, provides a sensitive measure of total ozone at the equator, where the sun is directly overhead and the column ozone amount is low. We use these equatorial measurements at this so-called "D-pair" wavelength to stabilize any long-term drift in calibration.

Because the SBUV data are now expected to have a stable calibration over time, we have used them to determine possible changes in the calibration of the TOMS instruments. We have adjusted all of the SBUV and TOMS measurements to a common calibration and produced a single merged data set that extends from November 1978 through the end of 2000. This data is available on the Web at http://code916.gsfc.nasa.gov/Data_services/merged/. For more information, contact Richard Stolarski (Richard.S.Stolarski.1@gsfc.nasa.gov).

National Polar Orbiting Environmental Satellite System

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the Source Evaluation Board, acting as technical advisors. Laboratory personnel were involved in evaluating proposals for the OMPS (Ozone Mapper and Profiler System) and the Crosstrack Infrared Sounder (CrIS), which will accompany ATMS, an AMSU-like crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operation Algorithm Teams (SOAT), which will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trade studies involving CrIS and ATMS, the advanced IR and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of AIRS to determine atmospheric CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2ppm (0.5%) from AIRS under clear conditions, total CH_4 to 1%, and total CO to 15%. This shows that AIRS should be able to produce useful information about atmospheric carbon. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

For OMPS, Laboratory scientists continue to support the IPO through the Ozone Operational Algorithm Science Team. The team conducts algorithm research and provides oversight for the OMPS developer. We are developing an algorithm to analyze SAGE III data when SAGE III operates in a limb scattering mode. We'll use the algorithm to simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE/LORE mission. The retrievals from this Shuttle mission demonstrated the feasibility of employing limb scattering to observe ozone profiles with high vertical resolution down to the tropopause. This research is enabled by the advanced UV and Visible (VIS) radiative transfer models developed in the Laboratory. Laboratory scientists also participate in the Instrument Product Teams to review all aspects of the OMPS instrument development. The IPO is supporting a reflight of SOLSE/LORE in the summer of 2001 as a risk mitigation effort related to the OMPS. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

CrIS is a high-spectral-resolution interferometer infrared sounder with capabilities similar to those of the Atmospheric Infrared Sounder (AIRS). CrIS will fly with AMSU A and the Humidity Sounder Brazil (HSB) on the EOS Aqua platform, to be launched in 2001. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. These data will be used in a pseudo-operational mode by NOAA/NESDIS and NOAA/NCEP. Simulation studies were conducted for the IPO to compare the expected performance of AIRS/AMSU/HSB with that of CrIS, as a function of instrument noise, together with AMSU/HSB. The simulations will help in assessing the noise requirements

for CrIS to meet the NASA sounding requirements for the NPOESS Preparatory Project (NPP) bridge mission in 2005. Trade studies have also been done for the Advanced Technology Sounder (ATMS), which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

Tropospheric wind measurements are the number one priority in the unaccommodated Environmental Data Records (EDR) identified in the NPOESS Integrated Operational Requirements Document (IORD-1). The Laboratory is using these requirements to develop new technologies and Direct Detection Doppler Lidar measurement techniques to measure tropospheric wind profiles on a global scale. The IPO is supporting the effort through their IGS program. For more information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The Instrument Incubator Program is supporting the development of a visible and infrared imaging radiometer based on advanced-technology array detectors. The goal is an imaging radiometer smaller, less costly, and more capable than previous instruments. The program is developing an instrument based on advanced microbolometer array (MBA) warm thermal detectors. A prototype MBA-based instrument, the ISIR, flew as a shuttle small attached payload in August 1997. Its performance proved the capability and advantages for MBA detectors in space applications. The Compact Visible and Infrared Imaging Radiometer (COVIR) is an engineering model of an operational flight instrument and will be completed and tested in 2001. A shuttle flight experiment is planned for early 2003. For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The IPO supports the development of Holographic Scanning Lidar Telescope technology as a risk reduction for lidar applications on NPOESS, including, but not limited to, a direct detection (edge) wind lidar system. Currently used in ground-based and airborne lidar systems, holographic scanning telescopes operating in the visible and near infrared wavelength region have reduced the size and weight of scanning receivers by a factor of three. We are currently investigating extending the wavelength region to the ultraviolet, increasing aperture sizes to 1 meter and larger, and eliminating all mechanical moving components by optically addressing multiplexed holograms in order to perform scanning. This last development should reduce the weight of our current large aperture scanning receivers by another factor of three. For more information, on the Holographic Optical Telescope and Scanner (HOTS), visit the Web site at http://virl.gsfc.nasa.gov/lazer/index.html or contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers, the project scientist and the project manager, who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large.

Table III lists project and deputy project scientists for current missions.

Table III: Laboratory for Atmospheres Project and Deputy Project Scientists

Name	Project	Name	Project
Pawan K. Bhartia	TOMS	Anne R. Douglass	UARS, EOS Aura
Dennis Chesters	GOES	Ernest Hilsenrath	EOS Aura
Jay Herman	Triana	Arthur Hou	TRMM
Yoram Kaufman*	EOS Terra	Si-Chee Tsay	EOS Terra
Robert Adler	TRMM		
Charles Jackman	UARS		
Mark Schoeberl	EOS Aura		
Joel Susskind	POES		
Robert Cahalan	EOS SORCE		

Name	Project	Name	Project
David O'C. Starr	EOS	Matt McGill	Cloud Sat
		Matt McGill	PICASSO-CENA
		P. Newman, M. Schoeberl	SOLVE
		Anne Thompson	SONEX
		Si-Chee Tsay	SAFARI-2000
		Si-Chee Tsay	PRiDE
		Lorraine Remer	PRiDE
		James Spinhirne	SPARCLE

* Through September, 2000, current Project Scientist is Jon Ranson, Code 920.

Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory depends on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community, as shown in Appendix 5.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs residing at universities or other federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 7, reflects our many scientific interactions with the outside community; 70% of the publications involve co-authors from institutions outside the Laboratory.

Prime examples of collaboration between the academic community and the Laboratory include these cooperative agreements with universities:

- Earth System Science Interdisciplinary Center (ESSIC), with the University of Maryland, College Park;
- Joint Center for Earth Systems Technology (JCET), with the University of Maryland, Baltimore County;
- Goddard Earth Sciences and Technology Center (GEST Center), with the University of Maryland, Baltimore County, (and involving Howard University);
- Center for Earth-Atmosphere Studies (CEAS), with Colorado State University;
- Cooperative Center for Atmospheric Science and Technology (CCAST), with the University of Arizona;
- Cooperative Institute for Atmospheric Research (CIFAR) Graduate Student Support, with UCLA; and
- Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA), with Howard University.

These joint centers have been organized to increase scientific interactions between the Earth Science Directorate at GSFC and the faculty and students at the participating universities.

University and other outside scientists visit the Laboratory for periods ranging from one day to as long as two years. (See Appendix 1 for list of recent visitors and Appendix 4 for seminars.) Some of these appointments are supported by Resident Research Associateships offered by the National Research Council (NRC) of the National Academy of Sciences; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the Goddard Earth Sciences and Technology (GEST) Center. Visiting Scientists are appointed for up to two years and carry out research in pre-established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design. (See Appendix 3 for a list of NRC Research Associates, GEST Center Visiting Scientists, Visiting Fellows, and Associates of the Joint Institutes during 2000.)

Interactions with Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA centers and federal laboratories.

Our ties with the other NASA centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the agency's scientific objectives.

Our interactions with other federal laboratories enhance the value of re[illegible]nded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground truth activities for satellite missions, and operational satellites. An example of interagency interaction is the new NASA/NOAA/NSF Joint Center for Satellite Data Assimilation (JCSDA), which will expand prior collaborations between NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

Interactions with Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the TRMM Mission, with the Japanese National Space Development Agency (NASDA); the Huygens Probe GCMS, with the ESA (CNES); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia.

Laboratory scientists interact with about twenty foreign agencies, about an equal number of foreign universities, and two foreign companies. The collaborations vary from extended visits for joint missions to brief visits for giving seminars or, perhaps, working on papers. Following the joint US-Japan Workshop on Relationships and Intercomparison of Monsoon Climate Systems, held in our Laboratory, participants agreed to develop pilot research projects involving the US Global Change Research Program and the Japanese Frontier Research System for Climate Variability to enhance studies of teleconnections or globally connected climate systems.

Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports government/industry partnerships, SBIR's, and technology transfer activities. For example, the Goddard Technology Utilization Office (through a contract with Research Triangle) performed an assessment of the Shared Aperture Multiplexed (SAM) Holographic Telescope Invention Disclosure and is pursuing a patent on the invention. We have engaged Houston Advanced Research Center (HARC) and TerraPoint LLC as commercial partners for developing airborne lidar altimetry (terrain mapping) applications of the SAM technology. SAM technology enables large aperture scanning without the use of moving mechanical components. SAM is lighter, by an approximate factor of three, than our previous holographic scanning technology, or an order of magnitude lighter than an equivalent conventional scanning optical telescope. The current concept for the terrain mapping application is to use several wide-field-of-view Holographic Optical Elements (HOEs) multiplexed into a single optic with linear avalanche photodiode arrays to essentially create a push-broom lidar terrain imager. This technology is also contemplated for atmospheric lidar applications such as tropospheric wind sounders.

The Commercial Utilization Office co-sponsored the development of a concept for a low-cost satellite attitude-determination system. This technique will be employed by the ozone monitor to fly on NPOESS. A patent application has been filed.

Matt McGill was presented with the James J. Kerley Award for the year 2000 for his outstanding contributions to technology commercialization. The award is the highest given by the Technology Commercialization Office each year. Matt is the second winner of the award from the Laboratory for Atmospheres.

Successful technology transfer has occurred on a number of other programs in the past and new opportunities will become available in the future. Past examples include the Micro Pulse Lidar (MPL) and holographic optical scanner technology. Industry now develops and markets micro-pulse lidar systems to an international community. Twenty units have been sold and deployed thus far. A licensing agreement with industry permits the use of government-patented holographic telescope technology for commercial application in topographic mapping. New research proposals involving technology development will have strong commercial partnerships wherever possible. The Laboratory hopes to devote at least 10% to 20% of its resources to joint activities with industry on a continuing basis.

6. HIGHLIGHTS OF LABORATORY FOR ATMOSPHERES ACTIVITIES IN 2000

What sort of results do we get from our work? In this section, you'll learn about the Laboratory's accomplishments for 2000. We have divided this material into two groups. First, you'll see a branch-by-branch summary of highlights. Then, you'll see short articles presenting the results of specific science research highlights.

Summary of Branch Highlights

Data Assimilation Office (DAO), Code 910.3

The Data Assimilation Office (DAO) works to advance the state of the art of data assimilation. The DAO's objectives are:

- To produce research-quality assimilated data sets for addressing questions in studies of the Earth system and of global change
- To make the best use of satellite data for climate assessment
- To assist Earth Observing System science and instrument teams

The DAO's accomplishments in 2000 include—

1) The DAO made major upgrades to the global data assimilation system in use (GEOS), including development of a new version of the core atmospheric circulation model. The upgrades included the following:
   - A revised software architecture (enabling a tropospheric configuration of 1^0x 1^0 and 48 levels, and a stratospheric configuration of 2^0x 2.5^0 and 70 levels)
   - A revised hydrodynamics core
   - Advanced parameterizations of physical processes.

   The latter involved a relaxed Arakawa-Schubert convective scheme, a Mellor-Yamada-type moist-turbulence parameterization, the land-surface model of Koster and Suarez, the long-wave and short-wave radiation scheme of Chou and Suarez, and orographic gravity-wave drag from Zhou et al. A particularly important aspect of GEOS is the physical-space statistical analysis system that provides a global analysis with minimal data selection questions in grid-point space (equivalent to a 3DVAR scheme). Other features are interactive quality control, adaptive estimation of forecast error variance statistics, and non-separable forecast error correlation functions. The interactive quality control of observations enables extreme events to be better captured, with a demonstrable impact from data that would otherwise be rejected. On-line forecast bias correction yields unbiased analyses (especially important for instrument teams). A rapid update cycle (one hour), employed experimentally, improves usage of all asynoptic data, eliminates a spurious tidal signal from analyses and is expected to improve the representation of the hydrological cycle in general. This rapid update cycle is a cost-free partial alternative to 4DVAR.

   The DAO developed two main advances for the GEOS system:

   - A first-look analysis, providing operational support to Mission to Earth Science Enterprise Satellites, especially Terra; e.g., for developing instrument retrieval algorithms

- Final platform analyses using the same information as the first-look analyses together with additional data from Mission to Planet Earth platforms (expected to change as the assimilation system and data availability from the platforms evolve).

2) The DAO further analyzed the impact of including or excluding specific data sets. This analysis has led to significant improvements in the representation of the hydrological cycle and atmospheric energetic terms in the GEOS analyses resulting from the assimilation of TMI and SSM/I rain-rates, as well as total precipitable water. These improvements have resulted in better cloud, moisture, and latent heating distributions in the tropics, and consequently reduced biases in radiative fluxes. Synoptic features were also better represented, and improved forecasts of tropical precipitation (beyond one day) and five-day forecasts generally in the tropics were obtained from the analyzed states. Initial tests using data from QuikSCAT have shown great potential: this is a further example of the major role that can be played by data assimilation in the use, retrieval, and full exploitation of all types of remotely sensed data.

Mesoscale Atmospheric Processes Branch, Code 912

The Mesoscale Atmospheric Processes Branch seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. The Branch studies the physical and dynamical structure and evolution of a broad range of meteorological phenomena ranging from the synoptic scale down to micrometeorology. Branch research focuses on the initiation, development, and effects of cloud systems, such as storms and other climatically significant cloud forms. The major emphasis is on energy exchange and conversion mechanisms associated with turbulence, convection, cloud-scale, mesoscale, and regional-scale phenomena. The work is inherently focused on defining atmospheric components of the global hydrologic cycle and understanding their interaction with other components of the Earth system.

The Branch's accomplishments in 2000 include—

1) Branch scientists derived global precipitation data using satellite observations from the Tropical Rainfall Measurement Mission (TRMM) and earlier and continuing SSM/I and GOES observations, rain gauge networks, and ground-based radar. Branch scientists are heavily engaged in all phases of fieldwork, supporting validation of satellite-derived precipitation estimates including application of an airborne (NASA ER-2) Doppler precipitation radar (EDOP). The Branch is also strongly engaged in future missions such as the AMSR-E on EOS Aqua, to be launched in 2001, and the developing Global Precipitation Mission (GPM).

   A major effort has been made to characterize the rainfall data products generated by different instruments on the TRMM satellite. Data products generated by the passive microwave (TMI) and the active precipitation radar (PR) sensor have been rigorously compared over the globe for the 2.5-year record. This analysis is a key step toward a best estimate of precipitation climatology; i.e., algorithm characterization and improvement and ultimately uniform optimal reprocessing of the data over the mission life.

The spatial and temporal distribution of rainfall over the Amazon basin has been derived from 30-minute 4-km GOES infrared observations calibrated against retrievals from the TRMM Microwave Imager on TRMM. This calibration has enabled the Branch to characterize the diurnal cycle of rainfall, its spatial distribution in response to heterogeneous surface conditions, and the nature of the rainfall (convective versus stratiform).

2) The Branch is active in making measurements of mesoscale and cloud-system structure and processes. Branch members are heavily engaged in developing lidar technology. Lidars allow us to measure an array of atmospheric characteristics at fine temporal and spatial resolution, from airborne platforms, from satellite platforms, and from the ground. For instance, the Cloud Physics Lidar (CPL) characterizes the profile structure of cloud systems. The Micro Pulse Lidar (MPL), the Large Aperture Scanning Airborne Lidar (LASAL), and most other lidar systems enable us to measure atmospheric aerosols. The Scanning Raman Lidar (SRL) and Raman Airborne Spectroscopic Lidar (RASL) allow us to characterize water vapor. Finally, the Goddard Lidar Observatory for Winds (GLOW) enables us to characterize winds. Of particular note are capabilities to characterize atmospheric structure in the planetary boundary layer and in upper tropospheric cirrus clouds. A key activity is the central role played by Branch scientists in the development of the atmosphere-sensing capabilities of the GLAS system that will be launched on ICEsat late in 2001. Branch scientists are also involved in the PICASSO-CENA (lidar) and CloudSat (mm-radar) missions that are planned for launch in 2003.

A major accomplishment was the rapid development and integration of the Cloud Physics Lidar, successor to Cloud Lidar System, for flights on the NASA ER-2. This new and greatly improved instrument incorporates recent technology advances to facilitate improved sensing capabilities and data products at reduced size and weight. The CPL permits vastly more rapid production of calibrated science-quality data sets (days versus months). The system was deployed to the SAFARI-2000 field experiment, a major international experiment and a core validation activity for the EOS Terra mission. CPL captured valuable data sets characterizing the complex layered structure of aerosol within the southern African gyre. CPL has already assumed its role as a key airborne sensor for studies of aerosols and cloud systems, especially in development and validation of algorithms for application to present and future satellite-based measurements.

Another highlight was the successful field tests of the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE). The mechanical simplicity and high fidelity of this new lightweight "telescope" technology has great promise in future lidar-based remote-sensing.

3) The Branch is active in modeling mesoscale cloud systems. Atmospheric dynamics models represent our best understanding of atmospheric processes and provide the capability of studying these processes and their interactions in ways not possible with observations, e.g., establishing cause and effect. A suite of overlapping cloud-system models has been developed that spans a range of scales and processes. The suite includes a state-of-the-art mesoscale model (MM5) that allows regional studies of weather systems at sub-synoptic scales, a cloud system model (GCE) that allows high-resolution studies of cloud systems with special emphasis on precipitating deep convective clouds, and very-high-resolution cirrus cloud models. These models can be coupled to a comprehensive land-surface (vegetation) model and an ocean model to study the interactions of surface processes with the overlying atmosphere.

The Branch has produced high-resolution simulations of hurricanes with MM5, using a spectrum of boundary-layer parameterizations to establish the strong sensitivity of hurricane intensity and structure to surface fluxes. Detailed analysis indicates that horizontal eddy transports into the eye region play a key role in storm intensification and precipitation structure, in agreement with recent theoretical arguments.

Branch study of convective triggering and the role of land-surface heterogeneity indicate that cumulus parameterizations should be applied over multiple individual landscape patches within a GCM grid box, rather than to the grid box as a whole, as occurs in present climate system models.

Branch scientists actively participate in and lead international model comparison and evaluation activities of the GEWEX Cloud System Study. These activities aim to increase confidence in these tools and facilitate research on the development and testing of cloud parameterizations used in large-scale climate and forecast models (GCMs).

The Branch has developed a visualization lab and Electronic Theater that is being increasingly used in high-profile settings to reach out to scientists and, importantly, to citizens and government organizations to stimulate understanding and support of NASA's Earth Science Enterprise and its endeavors. The lab's capabilities are heavily employed by the TRMM Outreach Office, a group that has had a remarkable year in bringing the value of TRMM and TRMM-science to the forefront of US global change research. The American Meteorological Society (AMS) includes the Branch's Electronic Theater in all its annual meetings.

Climate and Radiation Branch, Code 913

The Climate and Radiation Branch conducts research on the causes and consequences of regional and global climate variability. The Branch focuses on underlying physical processes, especially those associated with the formation of aerosols, clouds, and precipitation, and their interaction with atmospheric dynamics and radiation. Research is carried out using a combination of data from space-based as well as ground-based data in parallel with a hierarchy of models from cloud-resolving scales to global system models.

The Branch's accomplishments in 2000 include—

1) Branch scientists use satellite and remote-sensing data to improve our understanding of the physical processes responsible for the formation of clouds, precipitation and their interactions with the water and energy cycles.

   They found new evidence of climate sensitivity to global warming based on satellite data that demonstrated decreasing high-level clouds over the tropical western Pacific as the mean sea surface temperature of the cloudy region increases. Branch scientists developed an improved rain retrieval method based on spatial structures of the TRMM microwave radiometer (TMI) observations. The method will provide better discrimination of convective and stratiform precipitation. Branch scientists also developed a simple method of estimating mean squared random error in monthly rainfall estimates, based on quantities that can be directly computed from the satellite data. This method will have potential application in the design of the Global Precipitation Mission (GPM).

2) Branch scientists developed better retrieval techniques for optical and radiative properties of aerosols and clouds to assess their impact on climate change.

Using preliminary data from Terra, Branch scientists demonstrated for the first time that we can use the combination of aerosol measurements from MODIS and MISR, carbon monoxide measurements from MOPITT, and energy measurements from CERES to distinguish man-made combustion aerosol from natural aerosol. This capability will allow us to identify fingerprints of human impact on climate change. Branch members streamlined the Terra data system to allow the Forest Service to use MODIS images for monitoring the wildfires of August 2000 in Montana and Idaho. This use of Terra data permitted unprecedented near-real-time (within 15 hours) observations of fires, smoke, and the spread of pollution. The Branch also conducted international model-comparison projects that documented significant inter-model differences in the cirrus cloud models used in global climate studies.

3) Branch scientists continued their modeling and diagnostic studies to better understand the mechanisms of climate variations, climate processes, and predictability.

They demonstrated that remote forcing from radiative cooling in the subsidence region exerts strong control on the cloudiness distribution in the warm pool region, and that the gradient of SST likely plays an important role in controlling cloud radiative feedback associated with global warming. Branch scientists identified the impact of El Niño on the occurrence of regional floods and droughts. Their findings demonstrate that extreme precipitation events over Asia and North America may be connected through climate teleconnections. Branch scientists proposed a new interpretation of monsoon mechanisms based on atmospheric general circulation experiments, developed a new generation catchment-based land-surface model for use in climate studies, carried out experimental dynamical seasonal predictions with a state-of-the-art production version of the NSIPP atmospheric GCM, and developed a new parameterization for snow cover. Their new approach to snow cover included separate predictions of the temperatures of snow and the ground underneath. These advances promise better climate simulations in atmospheric general circulation models.

4) The Branch developed advanced concepts for furthering research and technology into operational programs and projects.

Branch members championed and submitted a proposal to NASA Headquarters for establishing a Center of Excellence for Aerosol Climate Research within the Laboratory. Branch members also developed a science plan and methodologies to deploy an advanced imaging instrument to retrieve information about the effects of aerosols on cloud reflectivity, for the first Earth-viewing satellite, Triana, at the L-1 point. The Branch conducted an international workshop on "Inter-comparison of 3-dimensional (3D) Radiation Codes" with five goals :

- To understand the errors and limits of 3D methods
- To provide 'baseline' for future 3D code development
- To promote sharing of 3D tools
- To derive guidelines for 3D tool selection
- To improve atmospheric science education in 3D radiation

Branch members also fabricated a laboratory instrument, the THOR lidar, which is designed to measure cloud thickness from off-beam lidar returns. The instrument is being

prepared for airborne deployment and for competitive award under the Instrument Incubator Program (IIP).

Atmospheric Experiment Branch, Code 915

The Atmospheric Experiment Branch conducts experimental studies to increase our understanding of the chemical environment in our solar system during its formation and to study the physical processes that have continued to shape solar system bodies through time. To achieve this goal, the Branch has a comprehensive program of experimental research, developing instruments to make detailed measurements of the chemical composition of solar system bodies such as comets, planets, and planetary systems that can be reached by space probes or satellites.

The Branch's accomplishments for 2000 include—

1) The Branch continued participation in the CONTOUR mission that will rendezvous with three comets and provide a more detailed understanding of the cometary nuclei and the diversity among comets. Branch members are building a Neutral Gas and Ion Mass Spectrometer (NGIMS) in-house. Scheduled delivery of the instrument is September 2001 with a launch in July 2002. The NGIMS instrument team successfully completed both a preliminary design review and a critical design review during the past year. The instrument design and parts fabrication have been completed and instrument assembly is underway.

2) The Branch continued providing post-launch support for several key planetary missions. These include—

- A Gas Chromatograph Mass Spectrometer on the Cassini Huygens Probe mission to explore the atmosphere of Saturn's moon Titan

- An Ion and Neutral Mass Spectrometer on the Cassini Orbiter to explore the upper atmosphere of both Saturn and Titan

- A Neutral Mass Spectrometer on the Japanese *Nozomi* mission to explore the upper atmosphere of Mars.

   In addition, Branch members continue to refine flight data from the Galileo Probe Neutral Mass Spectrometer.

3) Branch members submitted instrument proposals for two Discovery missions. One mission, the Venus Atmosphere Measurement Probe, entails an entry probe mission to explore the lower atmosphere of Venus. The Branch will provide a mass spectrometer for this mission. The second mission is called Odyssey. Odyssey will rendezvous with the Comet Kopff. The Branch will provide a gas chromatograph mass spectrometer similar to the one that would have flown on the cancelled Champollion mission.

4) An important collaborative effort with GSFC's Engineering Directorate has been initiated during this past year. This collaboration calls for a comprehensive program to achieve a significant reduction in the size and weight of present-day mass spectrometer systems by using MEMS technology. The effort will unfold in two steps: The first step is to use Application Specific Integrated Circuits to reduce the size and weight of the electronics. The second step will use the GSFC in-house skills and facilities to develop a miniaturized MEMS mass spectrometer. This effort will be expanded next year to promote collaboration with universities.

Atmospheric Chemistry and Dynamics Branch, Code 916

The Atmospheric Chemistry and Dynamics Branch conducts research in understanding the distribution and variability of atmospheric ozone by making new measurements, by analysis of existing data, and by theoretically modeling the chemistry and transport of trace gases that control the behavior of ozone. An emerging research focus is the characterization of sources and sinks of aerosols and other atmospheric trace gases that control global air quality.

The Branch's accomplishments for 2000 include

1) Branch scientists took the lead in organizing and conducting several aircraft and field campaigns, including the recently concluded SOLVE (SAGE III Ozone Loss and Validation Experiment) mission, designed to better understand the causes of ozone loss in the Arctic. Branch scientists provided a key instrument for this mission—the AROTEL lidar—developed in collaboration with Langley Research Center scientists to measure aerosol, ozone, and temperature above the aircraft cruise altitude.

2) Branch scientists have used data from the TRMM and UARS satellites as well as aircraft and balloon measurements to investigate the processes that regulate water vapor in the tropical upper troposphere. We have begun looking at processes occurring at the tropical tropopause that regulate stratospheric humidity. Our goal is to understand how human-induced climate change will affect these processes and, thereby, change the water vapor abundance of the stratosphere.

3) Branch scientists developed new techniques for measuring tropospheric aerosols, clouds, ozone, and air quality using a new generation of space-based instruments. Some of these ideas were incorporated in the scientifically enhanced Triana satellite mission. These enhancements were key factors in the National Academy of Science's decision to endorse the mission. Two ESSP missions based on these ideas are being developed, and more sensitive instruments to measure carbon dioxide from space are in the planning stage. NASA Headquarters selected several Branch scientists as members of the OMI science team to implement these ideas and to lead the 15-member US science team. (OMI is a Netherlands-provided instrument, scheduled to fly on the EOS Aura satellite in the year 2003.)

4) Branch scientists developed a new technique for merging different types of satellite and ground-based data to create a homogeneous long-term record of the total column ozone. This data set will play a key role in the upcoming international assessment of the health of the ozone layer. This congressionally mandated study is due in 2002 and will report on whether the ozone layer has begun to recover in response to decreasing concentrations of CFCs and other ozone-destroying chemicals.

5) Branch scientists developed a new 20-year record of aerosols by improved analysis of TOMS UV reflectance data. This data set is the only global aerosol data over land and the only data that can separate UV-absorbing aerosols (e.g., smoke from biomass burning and mineral dust from the deserts) from other types of aerosols (e.g., sulfates).

6) Branch scientists developed a 20-year record of tropical troposphere column ozone using the TOMS data. This data set has highlighted the importance of tropical oscillations (South-Atlantic Oscillations, also known as El Niño, and the quasi-biennial oscillations in longitudinal winds) in determining the distribution of tropospheric ozone. These natural signals mix with anthropogenic signals from biomass burning over Africa and South America to create a complicated spatial and temporal variability seen in the data record. To improve the understanding of these processes, the Branch scientists organized an international program called SHADOZ (Southern Hemisphere Additional Ozonesondes). This program aims at improving the quality and quantity of ozone vertical profile data in the region of the world that is experiencing rapid environmental change.

Scientific Research Highlights

Now that you've seen general summaries of our Branch accomplishments, let's have a closer look at the results of our research. The following pages present the Laboratory's scientific highlights for 2000, divided into three disciplines: Measurements, Data Analysis, and Modeling. Table IV lists the contents of these three sections.

Table IV: Summary of Scientific Research Highlights

Measurements	Data Analysis	Modeling
Ground-Based Measurements	**Aerosol Studies**	**Data Assimilation**
Surface Measurements for Atmospheric Radiative Transfer (SMART) Si-Chee Tsay, Code 913	**Operational Use of MODIS/Terra Data for Monitoring Fires in Montana and Idaho** Yoram Kaufman, Code 913	**Improving Four-Dimensional Global Data Sets and Short-Range Forecasts Using TRMM and SSM/I-Derived Rainfall and Moisture Observations** Arthur Hou, Code 910.3
MPL-Net James Spinhirne, Code 912	**Smoke Aerosol from Biomass Burning in Mexico, Hygroscopic Smoke Optical Model** Lorraine A. Remer, Code 913	**DAO Supports the SOLVE Mission** Steve Pawson, Code 910.3
Field Campaigns	**Clouds and Precipitation**	**The Predictability of Seasonal Means During Northern Summer** Siegfried Schubert, Code 910.3
SAGE III Ozone Loss and Validation Experiment (SOLVE) Paul A. Newman, Code 916	**Accuracy of TRMM Monthly Rainfall Maps** Thomas L. Bell, Code 913	**An Analysis of the Madden-Julian Oscillation** Siegfried Schubert, Code 910.3
Field Campaigns, PRiDE, SAFARI-2000, and ACE-Asia Si-Chee Tsay, Code 913	**Effect of Radiative Cooling on the Relation between Cloud and Sea Surface Temperature** Chung-Hsiung Sui, Code 913	**GEOS Ozone Data Assimilation System** Lars Peter Riishojgaard, Code 910.3
SAVE/SAFARI-2000 Ozonesonde Launches in Lusaka, Zambia Anne M. Thompson, Code 916	**The Use of Vegetation for Estimating Broken-Cloud Optical Properties from Surface Radiance Measurements** Alexander Marshak, Code 913	**Land Temperature Assimilation** Arlindo da Silva, Code 910.3
Airborne ER-2 Cloud Physics Lidar System Matt McGill, Code 912	**Effects of Clouds on the Solar Heating of the Atmosphere in the Tropical Western Pacific** Ming-Dah Chou, Code 913	**Hurricanes**
Instrument Development	**Climate Variability and Climate Change**	**Numerical Modeling of Hurricanes** Scott Braun, Code 912
Geoscience Laser Altimeter System (GLAS) James Spinhirne, Code 912	**A Multiyear Data Set of SSM/I Derived Global Ocean Surface Turbulent Fluxes** Shu-Hsien Chou, Code 912	**Physical Processes**
GSFC Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL) Thomas J. McGee, Code 916	**Planetary Sciences**	**Force-Restore Snow Physics in SSIB** Yogesh Sud, Code 913
	Galileo Mission Highlights Paul R. Mahaffy, Code 915	**Cirrus Cloud Models** David Starr, Code 912

Measurements

Ground-Based Measurements

Surface Measurements for Atmospheric Radiative Transfer (SMART)

Much of the Laboratory's research focuses on the remote sensing and retrieval of physical/radiative properties of Earth's atmosphere (e.g., clouds, aerosols, and molecular constituents) and surface (e.g., soil and vegetation). To capture this data, we are mobilizing an evolving suite of remote-sensing instruments. We call this suite SMART, signifying Surface Measurements for Atmospheric Radiative Transfer. We will combine SMART observations with those from satellite nadir overpasses at targeted areas.

The SMART, as shown in Figure 2, includes broadband radiometers, shadow-band radiometer, sunphotometers, solar spectrometers, a whole-sky camera, a micro-pulse lidar, and a microwave radiometer, as well as meteorological probes for atmospheric pressure, temperature, humidity, and wind speed and direction.

Figure 2. The SMART setup: (a) multiple shortwave longwave broadband radiometers, (b) shadow-band radiometer, (c) sunphotometers, (d) solar spectrometers, (e) micro-pulse lidar, (f) whole-sky camera, and (g) microwave radiometer, as well as (h) meteorological probes for atmospheric pressure, temperature, humidity, wind speed/direction and, surface moisture content (not shown).

During 2000, SMART was successfully deployed to the PRiDE and SAFARI-2000 campaigns. Adding to our instrument development, we have completed the 3S (Sun-Sky-Surface) photometer and LAS (Leonardo Airborne Simulator) spectrometer. The 3S fabrication was funded through GSFC/DDF, with the collaboration of the Biophysics Branch (Code 923) and the Detector System Branch (Code 553). The 3S proved its superiority over the aging Cimel sunphotometer during its deployment on SAFARI-2000 to the AERONET site at Mongu, Zambia. The 3S contains 14 discrete channels, covering from ultraviolet to shortwave-infrared spectral region. It scans the upper (atmosphere) and lower (surface) hemispheres during its operation, as depicted in Figure 3.

Figure 3. Current operation of the 3S photometer, in contrast with the 8-channel, filter-wheeled Cimel sunphotometer in the background.

To prepare for future space formation flights, we collaborated on the fabrication of a compact, low-power, low-cost, Earth-viewing spectrometer. Our partners in this work were scientists D. Reuter of Code 693 and J. Tucker of Code 923, and engineers M. Jhabvala of Code 550 and P. Shu of Code 553. This prototype spectrometer, named the *Leonardo* Airborne Simulator (LAS), flew successfully for the first time in NASA's ER-2 high-altitude aircraft during SAFARI-2000 campaign. Operating in a push broom mode, LAS obtains a 3-D data cube by scanning the image of a surface over the focal plane (one axis of the array for spectral and the other for spatial sampling). The scanning motion is provided by the aircraft trajectory. A state-of-the-art detector, 1024 × 1024 Indium Antimonide array, is used in the LAS focal plane. The detector covers the entire shortwave spectral region (0.4-5.0 µm, typical quantum efficiency >80% everywhere, with proper anti-reflection coating for $\lambda < 1$ µm) thereby avoiding excessive patching-together of spectra. Figure 4 depicts the LAS, consisting of two modules, integrated in the ER-2 research aircraft. LAS records a scene spectrally through a wedged filter (linear variable filter, LVF) placed close to the detector array.

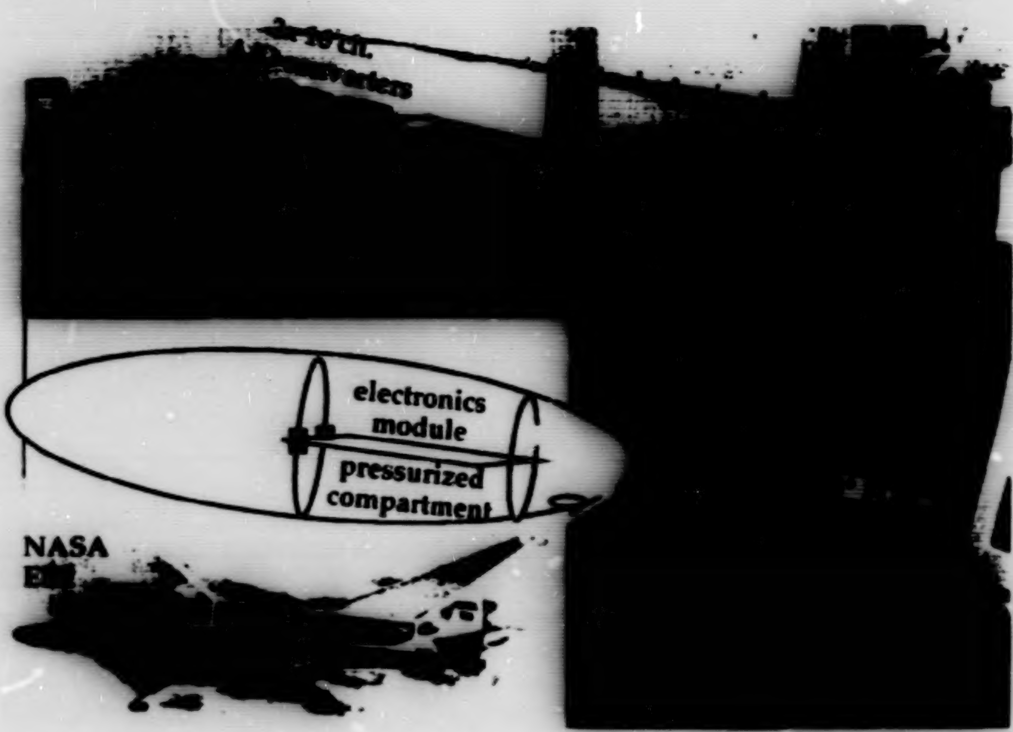


Figure 4. The LAS sensor subsystem (non-pressurized compartment, back portion of ER-2 super pod) contains the focal plane, imaging optics, and those electronics that must be near the detector arrays. Residing in pressurized compartment, the electronics module contains interface electronics that can be farther from the arrays.

In essence, the LVF achieves a spectral resolving power ($\lambda/\Delta\lambda$) of at least 500 (e.g., 1 nm at 0.5 µm and 5 nm at 2.5 µm), with the flexibility of having coarser resolution in some parts of the spectrum and finer resolution in others. The segmented wedged filter as the wavelength selective element on a single focal plane allows for a unique solution to the challenge of obtaining a wide field of view (90° FOV) over a broad wavelength range. Current optimal design of LAS uses the refractive module for simplicity and budgetary concern. This, however, is near the current limit for a single LVF segment in covering wavelength range of 0.4–2.5 µm. In the next stage, a reflective module will be sought to extend the full wavelength coverage with wide field of view, e.g., 120°.

Si-Chee Tsay, Code 913 (Si-Chee.Tsay.1@gsfc.nasa.gov)

MPL - Net

We have begun development of the world's first network of automated, full-time surface lidar observations of clouds and aerosols through a new project now funded by the EOS program. The network consists of micro-pulse lidar systems (MPL), which were developed, patented, and commercialized by the GSFC cloud and aerosol lidar group. The MPL network, named MPL-Net, currently consists of one site at the South Pole, one site at Goddard Space Flight Center, and four sites at Atmospheric Radiation Measurement (ARM) program locations. All MPL-Net sites are co-located with AERONET sunphotometers to acquire joint measurements of cloud and aerosol vertical distributions, optical depth, and sky radiance. Planning is underway for the installation of the next two MPL-Net sites in Saudi Arabia and Barbados. Other sites under consideration include locations in Japan, Korea, Taiwan, and Australia.

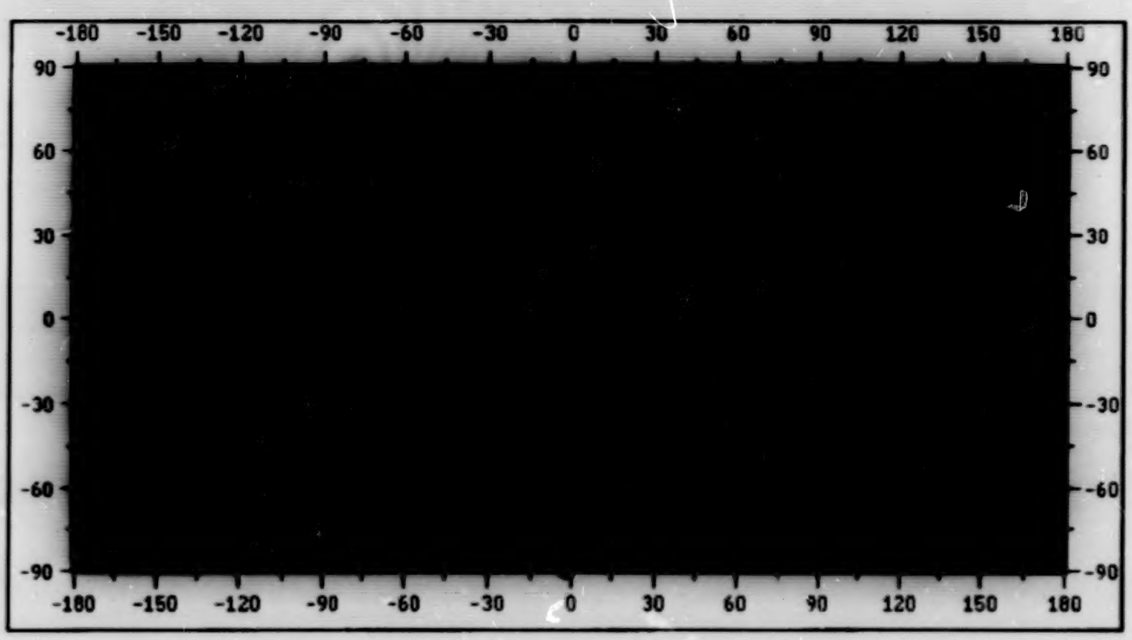


Figure 5. Map of existing and proposed MPL-Net sites. Recent field experiments and ship cruises are also shown. MPL-Net sites/experiments are shown with a circle, ARM sites with a black square, and ship cruises with a line. Existing sites are shown in red, proposed sites in pink, and experiments and cruises in pink.

In addition to the long-term site measurements, MPL-Net provides support for field experiments and ship cruises each year. The field experiments provide for an intensive study of cloud and aerosol properties by combining a variety of different measurement techniques. MPL-Net participated in three field experiments during the year 2000: an ARM cloud experiment in Oklahoma, the Puerto Rico Dust Experiment (PRiDE), and SAFARI-2000 in southern Africa. In the spring of 2001, MPL-Net will participate in the ACE-Asia experiment. During ACE-Asia one MPL will be deployed on board a research vessel and another in China in order to study the transport of Asian dust and pollution as it moves out over the Pacific Ocean.

The observations from MPL-Net will provide a unique data set for understanding the effects of clouds and aerosols on the atmosphere's radiation balance. For more information, see the MPL-Net Web site (http://virl.gsfc.nasa.gov/mpl-net/).

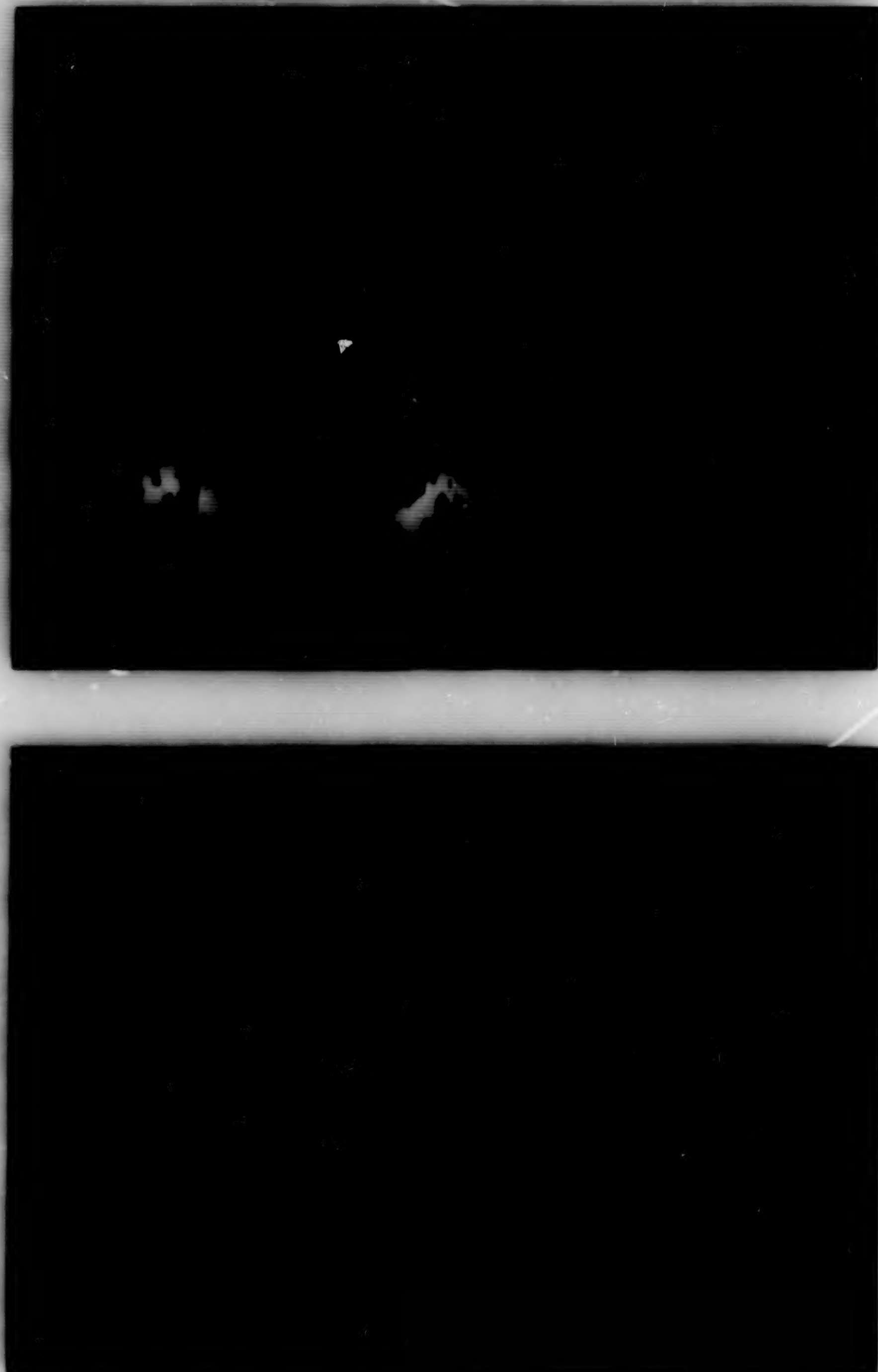


Figure 6. MPL data from the South Pole site on January 10, 2000. The upper graph shows MPL signals during the course of the day. The signal returns are from blowing snow and clouds at the site. The lower graph displays the particulate optical depth from the surface to 6 km. (On clear days the optical depth is near zero.)

James Spinhirne, Code 912 (James.D.Spinhirne.1@gsfc.nasa.gov)

Field Campaigns

SAGE III Ozone Loss and Validation Experiment (SOLVE)

During the winter of 1999-2000, the NASA-sponsored SAGE III Ozone Loss and Validation Experiment (SOLVE) was jointly conducted with the European Commission-sponsored Third European Stratospheric Experiment on Ozone (THESEO-2000).

This SOLVE/THESEO-2000 mission was designed to both investigate the processes that control polar and mid-latitude winter and spring ozone levels, and to validate measurements from the Stratospheric Aerosol and Gas Experiment (SAGE) instrument. Unfortunately, SAGE III was not launched on schedule, but SOLVE/THESEO-2000 was able to take advantage of our other satellite assets to understand polar ozone losses from this last winter.

The 1999-2000 Arctic stratospheric winter was very cold, leading to the appearance of extensive decks of polar stratospheric clouds (PSCs) across the Arctic lower stratosphere. The importance of these PSCs to the chemistry of the stratosphere is that they convert the reservoir species HCl and $ClONO_2$ into reactive forms of chlorine that can destroy ozone. In agreement with this chlorine conversion, extremely high levels of ClO were measured during the spring in the Arctic. These high chlorine levels led to ozone losses of about 60% in a layer near about 20-km altitude over the Arctic.

Although PSCs have been observed in the stratosphere for more than a century, there was actually little information on the particle sizes or composition. Direct observations using the NASA ER-2 and DC-8 aircraft have confirmed that these unique clouds are key components of the ozone loss process. Further, it is now understood how these cloud particles modify the stratosphere as they slowly fall. Such information will be applied in both diagnostic and assessment models for more accurate predictions of changes in stratospheric ozone.

The Laboratory for Atmospheres played a key role in the SOLVE/THESEO-2000 mission. Drs. Paul A. Newman and Mark R. Schoeberl helped develop the overall mission strategy and also served as project scientists for the mission. Forecasts, modeling, and flight planning work was provided by the Atmospheric Chemistry and Dynamics Branch. The Data Assimilation Office provided meteorological analyses and forecasts over the entire course of the mission from November 1999 through March 2000. The AROTEL Lidar system was also provided by the Atmospheric Chemistry and Dynamics Branch for flights on board the NASA DC-8. This lidar system was a joint effort of Drs. Thomas McGee and John Burris in association with Dr. Chris Hostetler of NASA LaRC. The lidar provided crucial information of polar ozone and temperature distributions during all three SOLVE deployments. Figure 7 shows ozone measurements taken during two flights in December 1999 and March 2000. The figure reveals a large decrease of ozone between December and March at an altitude near 18 km. This low ozone region results from catalytic destruction by chlorine and bromine species over the course of the winter and early spring. These chlorine and bromine species principally come from man-made compounds such as chlorofluorocarbons and halons.

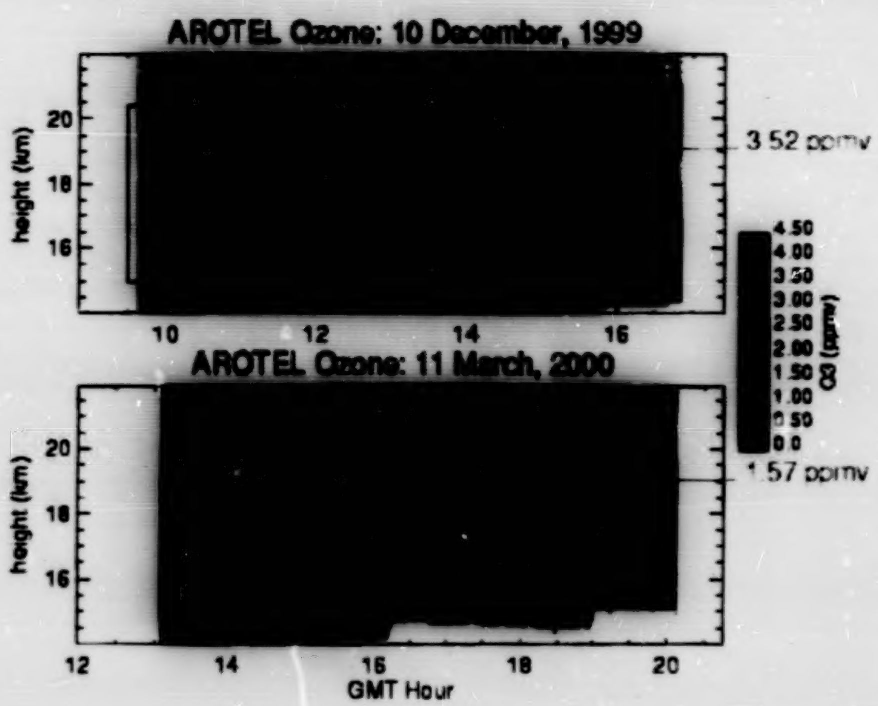


Figure 7. The figure shows ozone measurements taken during two SOLVE DC-8 flights in December 1999 and March 2000. The figures illustrate the large decrease in ozone between December and March at an altitude near 18 km

Paul A. Newman, Code 916 (Paul.A.Newman.1@gsfc.nasa.gov)

Field Campaigns, PRiDE, SAFARI-2000, and ACE-Asia

During 2000, we participated in two major field campaigns, PRiDE (Puerto Rico Dust Experiment) and SAFARI-2000 (Southern Africa Fire-Atmosphere Research Initiative), as part of the EOS science and validation tasks. We are also in the final planning stage for ACE-Asia (Aerosol Characterization Experiment-Asia), to be conducted in 2001. These field research activities are summarized below.

PRiDE, June-July 2000, in the vicinity of Puerto Rico

PRiDE was designed to measure the properties of Saharan dust transported across the Atlantic Ocean to the Caribbean. PRiDE is a collaborative endeavor with the Office of Naval Research and the University of Miami. In the summer months, moderate quantities of desert dust are observed in the Caribbean (cf. Fig. 8). Analyses of NOAA/AVHRR and EOS/AERONET data suggest that in June and July, mid-visible optical depth in the Caribbean can vary from 0.2 to 0.7, with a mean value of ~0.4. Puerto Rico is the first significant landfall for the dust traveling across the ocean from Africa. Other types of man-made aerosol pollutants, which may complicate the analysis, should not affect dust arriving on the eastern end of the island

Figure 8. Typical satellite imagery observed by SeaWiFS depicts the Saharan dust outbreak over Cape Verde Island (upper-right quadrant of left image) and transported to the vicinity of Puerto Rico Island (lower half of right image).

During PRiDE, we recorded aerosol optical thickness, precipitable water vapor, and downwelling irradiance. We gathered these measurements with the SMART suite of instruments and from a low-flying aircraft during the MODIS overpass. The data can reveal the extent to which we must know the properties of dust particles and the spectral surface reflectance of the ocean before we can use remote-sensing systems to accurately retrieve optical thickness and radiative flux. We will compare these ground-based observations with the MODIS retrievals over both land and ocean. In addition, we can use the time series of measurements in horizontal and vertical extent and horizontal homogeneity to evaluate model predictions of long-range transport and vertical distribution of African dust. Analyses of PRiDE measurements will lead us to a better understanding of dust's optical, microphysical, and chemical properties, especially the significant parameters of dust single-scattering albedo and nonsphericity.

SAFARI-2000, August-September 2000, in the vicinity of South Africa

SAFARI focused on biomass burning in the savannah region of southern Africa. A multi-national effort, SAFARI is a critical part of the EOS Terra (MODIS, MOPITT, MISR, CERES and ASTER) science and validation mission. While in the region, we also studied Namibian marine stratus clouds at the end of SAFARI-2000.

This experiment involved the NASA ER-2 aircraft as well as the University of Washington CV-580 and two aircraft from the South African Weather Bureau. Primary instruments of interest for the ER-2 are the MAS, MOPITT-A, AirMISR, SSFR, LAS, S-HIS (simulating Terra instruments), and CPL (a lidar for profiling the atmosphere). The ER-2 coordinated with *in situ* aerosol, radiation, and chemistry measurements on the CV-580 and overflew numerous AERONET locations in Namibia, Botswana, South Africa, Zambia, and Zimbabwe. The ER-2 also overflew the SAVE/SMART site in Skukuza, South Africa. SAFARI marked one of the most aggressive and successful coupled ground-based, *in situ*, and remote-sensing campaigns ever in Africa. The research focuses on land-atmosphere processes. We aim to discover how emissions from fires, biomass, and human activity affect the biogeophysical and biogeochemical systems of southern Africa.

The SAFARI data revealed information about (1) the vegetation structure and underlying geology associated with it, (2) the evolution of thick haze and ozone, and the intricate structures within them, and (3) the interactions of haze—whether caused by industrial, biomass burning, marine or biogenic sources—with local and distant cloud fields. We also observed what appears to have been an unprecedented southern African fire season, especially in western Zambia, southern Angola, northern Namibia, and northern Botswana. Extremely large fires were common, lasting weeks, with fire fronts often exceeding 30 km, and with total burned areas covering hundreds of square miles. We have managed to characterize the land surface and the atmosphere before, during, and after such fires. Integrated airborne and ground-based activities coupled with remote sensing data acquisition from Landsat-7 and Terra enabled the thorough observation of four prescribed fires—two in Zambia and two in South Africa. Thus, the Terra team will benefit from comparing SAFARI observations with its retrieved surface reflectance, fire, burned area, vegetation, LAI/FPAR, water vapor, cloud, and aerosol products.

ACE-Asia, March-May 2001, in the vicinity of Northeast Asia

The International Global Atmospheric Chemistry program has organized a series of aerosol characterization experiments (ACE) to acquire data sets needed for assessing aerosol effects in major regions of the globe. ACE-Asia is designed to study the compelling variability in spatial and temporal scales of both pollution-derived and naturally occurring aerosols. These aerosols often exist in high concentrations over eastern Asia and along the rim of the western Pacific. Phase-I of ACE-Asia will take place from March to May 2001, in the vicinity of the Gobi desert, the east coast of China, the Yellow Sea, and Japan, along the pathway of Kosa (severe events that blanket east Asia with yellow desert dust, peaking in the spring season).

Central Asia is one of the most important dust sources. However, the climatic impact of central Asian dust is less well studied than that of Saharan dust. Asian dust typically originates in desert areas far from polluted urban regions. During transport, dust layers can interact with man-made sulfate and soot aerosols from heavily polluted urban areas. Added to the complex effects of clouds and natural marine aerosols, dust particles reaching the marine environment can have properties drastically different from dust particles at the source. Thus, information about the unique temporal and spatial variations of Asian dust is of special importance in understanding regional-to-global climate issues such as radiative forcing, the hydrological cycle, and primary biological productivity in the mid-Pacific Ocean.

In collaboration with international chemists, our main goal in ACE-Asia is to use SMART instruments to continuously measure aerosol optical/radiative properties, column precipitable water, and surface reflectivity over homogeneous areas. Including flux measurements in our scope permits us to determine dust aerosol radiative flux, in addition to measuring loading and optical thickness. At the time of the MODIS overpass, these ground-based observations can provide valuable data to compare with MODIS retrievals over land. Even without dust events, the homogeneity of the Gobi desert serves as an excellent calibration target. Thus, SMART observations in the vicinity of dust sources are our first priority. A less instrumented SMART version will be set up in the marine environment.

Si-Chee Tsay, Code 913 (Si-Chee.Tsay.1@gsfc.nasa.gov)

SAVE/SAFARI-2000 Ozonesonde Launches in Lusaka, Zambia

As part of the SAVE component of SAFARI 2000, Laboratory staff launched balloon-borne ozonesondes in Zambia, Lusaka. The ozonesondes measured ozone, temperature, pressure, and relative humidity during the SAFARI-2000 dry season activity. Our objective was to validate tropospheric ozone data derived from the TOMS-EP satellite. The ozonesonde lab set-up was at the Zambian Meteorological Department (ZMD), where it was easy to put the ozonesonde-telemetry antenna on the adjacent roof and coordinate activity with the ZMD's radiosonde launches (taken twice daily at 1230 and 0030 local time).

The data gathered were outstanding because the burning of the late dry season took off at an explosive rate in late August and early September. These were the first ozone soundings taken in the heart of the central southern African burning region. The combination of stagnant conditions with intense local sources of ozone precursors produced peaks of > 100 ppbv ozone below 6 km and surface ozone > 70 ppbv at the end of a day. On the first sounding day there was a trash fire 50 meters from the ozonesonde launch site at ZMD (see Figure 9). Daily microTOPS (hand-held sun photometer) measurements of aerosol optical thickness were 1.5-2.0 in the visible-near UV. These aerosol and ozone values are higher than values seen at regular SHADOZ ozonesonde launching stations (e.g. Irene, South Africa, and Nairobi, Kenya) and SAFARI-1992 sites that are often hundreds of kilometers downwind from the densest fire activity.

Figure 10 shows tropospheric ozone derived from TOMS-EP for the September 8 launch. The triangle marks the location of the launch site in Lusaka (15.4S, 28.3E). The ozonesonde profile for the tropospheric portion of the flight (right panel) is in excellent agreement with the satellite-derived tropospheric ozone. Representing the burning season in southern Africa, Figure 10 suggests that the heaviest burning occurred in western and eastern central Africa. TOMS also measures high smoke aerosol over these regions. Exit pathways for these pollutants are east to Madagascar and the Indian Ocean, and west over the Angolan escarpment. As the ozone and smoke head toward the Atlantic Ocean, they are lifted over the mountains and are concentrated over the eastern Atlantic in a region of sinking and recirculating air motions. The TOMS-EP satellite followed smoke and tropospheric ozone ("smog ozone") day-by-day from biomass fires as they were transported long distances from burning areas. Animations of ozone and smoke transport over southern Africa can be seen at http://www.gsfc.nasa.gov/gsfc/earth/environ/safari2000_1final.htm

The SAFARI-2000, Lusaka ground-truth effort discovered that, besides the well-known large fires over central African grasslands, urban fires produced serious pollution because of preparation of charcoal for burning trash, cooking, and heating. The haze layer (containing high levels of ozone - a component of smog) was heavier than we expected from these fires observed by ground-based researchers, the Terra and Landsat 7 spacecraft, and research aircraft.

The NASA projects served by this trip were (1) SHADOZ (Southern Hemisphere ADditional OZonesondes - http://code916.gsfc.nasa.gov/Data_services/shadoz/), and (2) SAVE, as part of (3) SAFARI-2000 (http://safari.gecp.virginia.edu/).

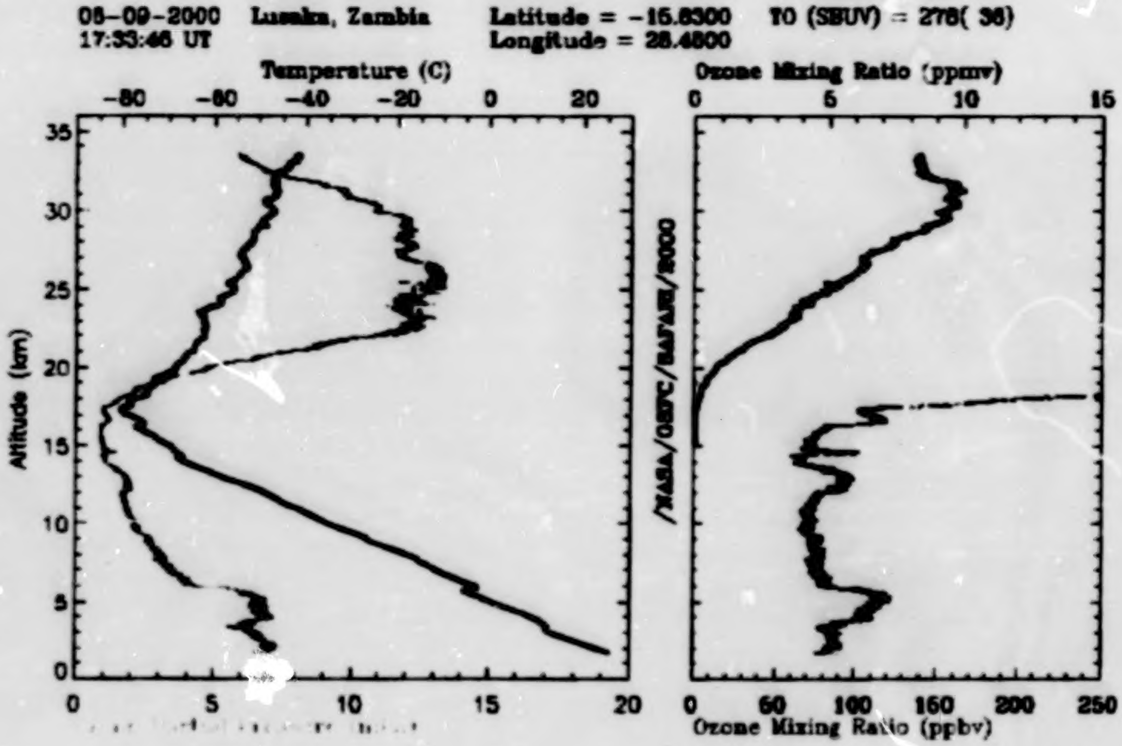


Figure 9. Ozone, water vapor, and temperature soundings taken in the heart of the central southern African burning region during SAFARI.

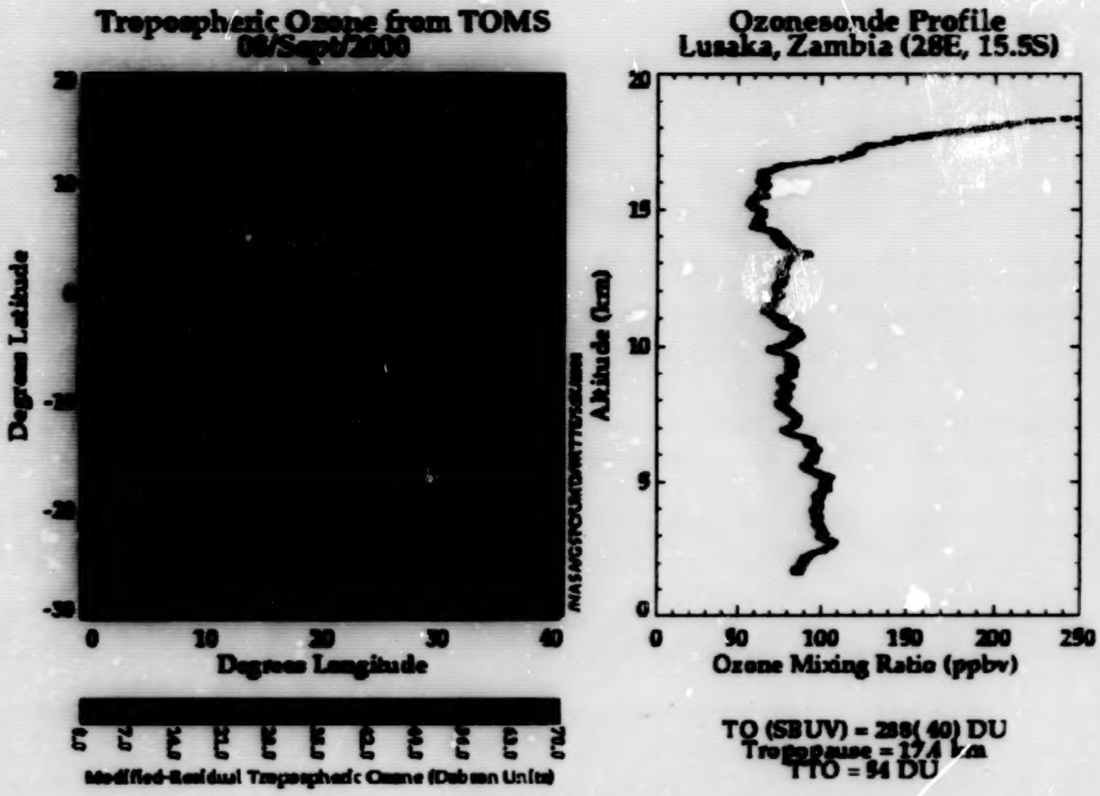


Figure 10. Tropospheric ozone derived from TOMS-EP for the September 8 launch during SAFARI.

Anne M. Thompson, Code 916 (Anne.M.Thompson.1@gsfc.nasa.gov)

Airborne ER-2 Cloud Physics Lidar System

During 2000, a new airborne lidar system was added to the Laboratory's instrumentation capabilities. The Cloud Physics Lidar (CPL) is specifically designed for use on the ER-2 aircraft and provides the first high-altitude photon-counting lidar capability. The CPL will enhance cloud and radiation studies by providing high-resolution profiles of clouds, aerosols, and smoke layers.

The CPL is a state-of-art system. It employs a solid-state, diode-pumped, conductively cooled laser operating at 5 kHz repetition rate. The laser simultaneously transmits 1064 nm, 532 nm, and 355 nm radiation. The receiver uses solid-state photon-counting detectors to measure the backscattered light at all three wavelengths. In addition, the 1064 nm signal is used for a depolarization measurement. Measuring the backscattered signal at three wavelengths provides information about cloud and aerosol optical properties. The depolarization measurement can be used to determine the molecular phase of clouds.

After construction, the CPL was immediately deployed on the SAFARI-2000 field campaign during August and September 2000. The purpose of SAFARI-2000 was to study aerosol and smoke layers over the southern African continent. During the SAFARI-2000 campaign, 19 science missions were flown, producing nearly 100 hours of data. The CPL functioned properly on all flights and the resulting data show remarkable detail of the boundary layer aerosol and smoke layers that prevailed over the African continent. Figure 11 displays a typical example of the CPL data, showing the intense boundary layer aerosol and stratified smoke/aerosol being lifted high into the atmosphere, as well as intermittent clouds.

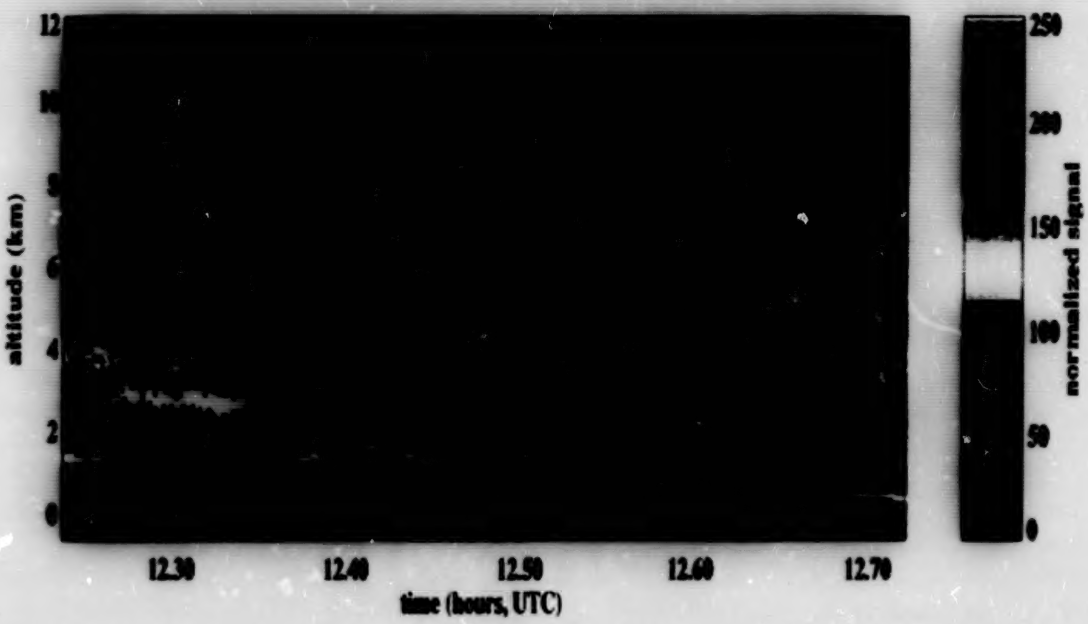


Figure 11. Example of 532 nm CPL data from SAFARI-2000 campaign, September 17, 2000. Data shows a complicated atmosphere including boundary layer aerosol and smoke, intermittent clouds, and smoke/aerosol being advected in at high altitudes. Data shown is normalized photon counts. Altitude is above sea level, and the bottom white line is the terrain profile. Cloud shadows are present whenever the lidar signal cannot penetrate through a layer.

Matt McGill, Code 912 (Matthew.J.McGill.1@gsfc.nasa.gov)

Instrument Development

Geoscience Laser Altimeter System (GLAS)

Global spaceborne lidar profiling of the true height structure of clouds and aerosol in the atmosphere is within a year of reality. The EOS Geoscience Laser Altimeter System (GLAS) instrument is being completed at GSFC. The clouds and aerosol lidar research group has contributed to major parts of the instrument development and the development of science algorithms. Stan Scott is responsible for the assembly and testing of the 532-nm lidar receiver system. The lidar receiver system is to be completed in 2000.

We have completed the initial version of the data processing algorithms for the GLAS atmospheric science data products. These highly complex algorithms must be able to take data and produce measurement results in real time.

The GLAS instrument will measure the vertical structure of radiatively significant clouds and aerosols with sufficient vertical and horizontal resolution to resolve large-scale variability. The atmospheric structure will be measured full-time over the entire orbital cycle including sunlit and dark scenes. The processing and retrieval algorithms will produce seven core data products. These are: (1) atmospheric layer type and vertical location, (2) aerosol backscatter cross section profile, (3) cloud backscatter cross section profile, (4) aerosol extinction cross section profile, (5) cloud extinction cross section profile, (6) aerosol optical depth per layer, and (7) cloud optical depth per layer. Layer locations are a direct measurement result from lidar-scattering structure. The basic parameter that defines the integrated radiative influence of a layer is optical depth. The GLAS instrument will be able to sense layers up to an approximate total optical depth of two before the signal is extinguished. The vertically resolved structure of radiative forcing is directly related to the extinction cross section profile. Both the extinction cross section and optical depth are derived parameters that involve the height-resolved laser backscatter data and appropriate retrieval algorithms. A simulation of the GLAS 532 nm signal for nighttime and daytime conditions is given in Figure 12, using TOGA-COARE data.

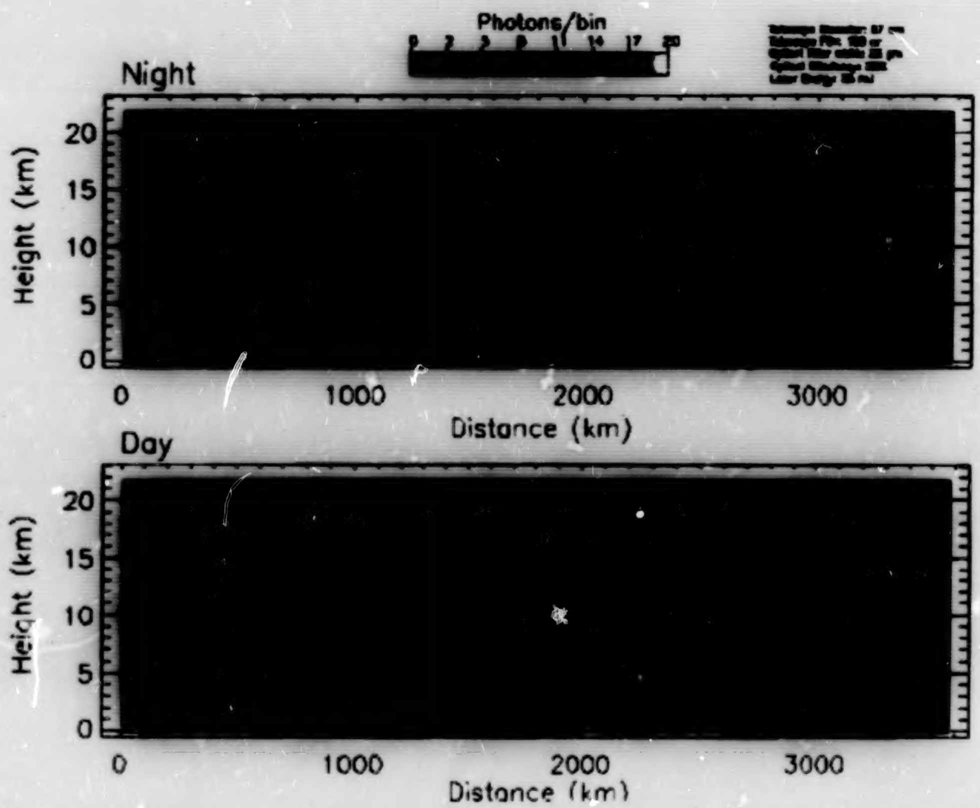


Figure 12. A nighttime (upper panel) and daytime (lower panel) simulation of the GLAS 532 nm signal using data from the TOGA-COARE experiment. The color coding is in terms of photons per bin (75 meters) as indicated on the color bar at the top.

James Spinhirne, Code 912 (James.D.Spinhirne.1@gsfc.nasa.gov)

GSFC Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL)

The GSFC Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL) is a new instrument that was developed for operation on board the NASA DC-8. AROTEL flew on its first mission during the SAGE III Ozone Loss Validation Experiment (SOLVE) in the winter of 1999 – 2000. The aircraft was deployed to Kiruna, Sweden, on three separate occasions throughout the winter, with approximately 7 flights into the Arctic vortex on each deployment.

The instrument is a collaborative effort between scientists at Goddard and Langley, a collaboration which has worked well and has resulted in a better system, scientifically, than would have been achieved if either group had proceeded on its own. The instrument is ideally suited for studies of ozone and clouds. The measured temperature provides important meteorological data, and the aerosol parameters measured at three widely spaced wavelengths constrain the calculations of microphysical properties within clouds (PSCs or tropical cirrus). The instrument generates a self-consistent set of data, in that the temperature and relative density profiles returned from the 355/387 data are used in the retrievals for aerosols and ozone mixing ratio. We are therefore not dependent on assimilations, which are based on data that could be twelve hours or more away from the lidar data.

Figure 13 shows data from the IR/Vis aerosol channels for the flight of Dec. 10, 1999. A thin NAT polar stratospheric cloud is seen at approximately 19-21 km at 13:50. NAT is typically thought of as forming near 195 K, but from Figure 14, we can see a large volume of the stratosphere with temperatures at 192 K with no PSCs evident. This data has spurred more research into the physics of PSC formation.

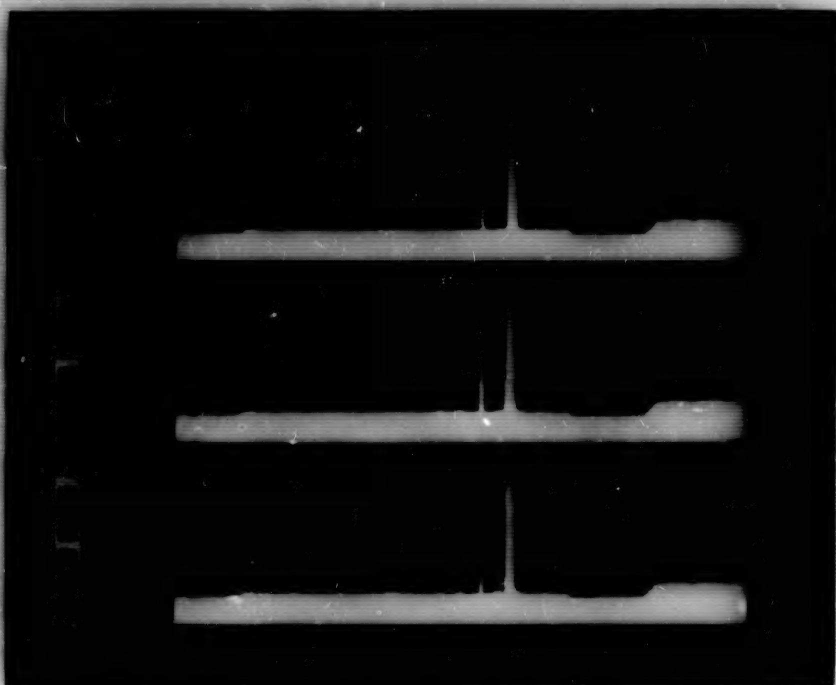


Figure 13. Aerosol scattering ratio data from 12/10/99. A thin liquid NAT cloud can be seen at ~13:50. Fine structure in the background aerosol is also seen.

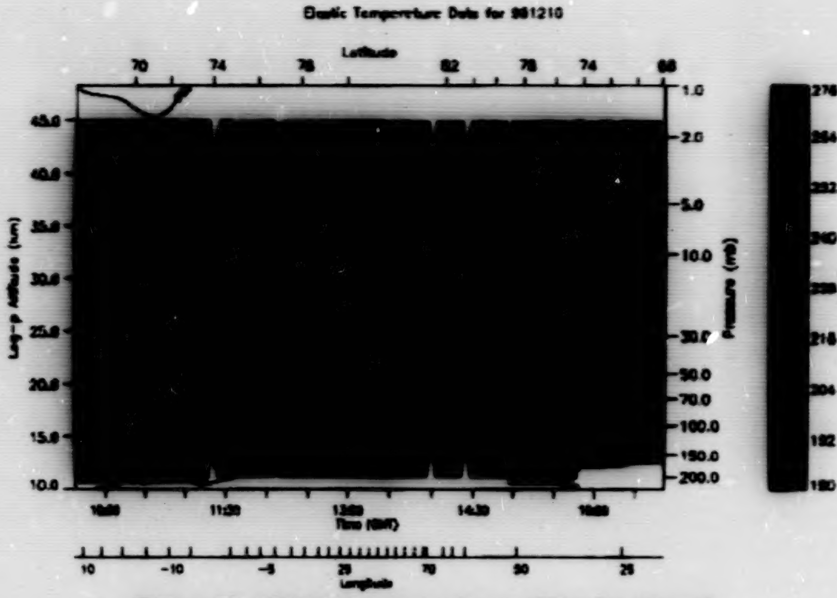


Figure 14. AROTEL temperatures above the aircraft.

The use of Raman scattering for the retrieval of temperatures in the presence of optically thin polar stratospheric clouds is a first for the DC-8. Figures 15 and 16 show the improvement achieved by using this technique as compared to using purely elastic scattering. Since Raman scattering depends only on the gas that provides the wavelength shift, there is no signature from aerosol scattering in these returns, only a slight effect due to extinction. When clouds are optically thin, the Raman return is representative of the atmospheric number density, and we can retrieve a reliable temperature.

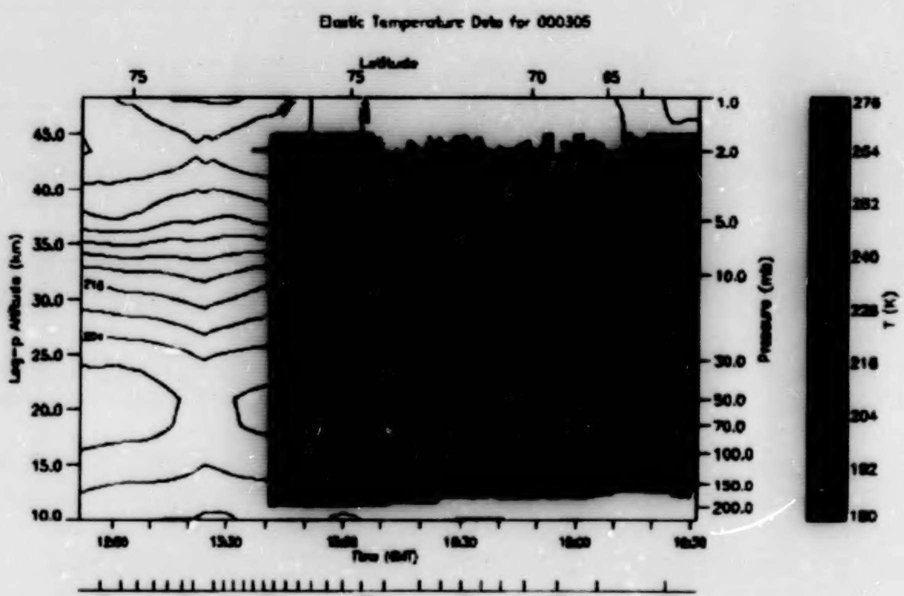


Figure 15. Temperature retrieved on March 5, 2000 using elastically scattered returns. Note the black, anomalously cold areas where PSCs are present.

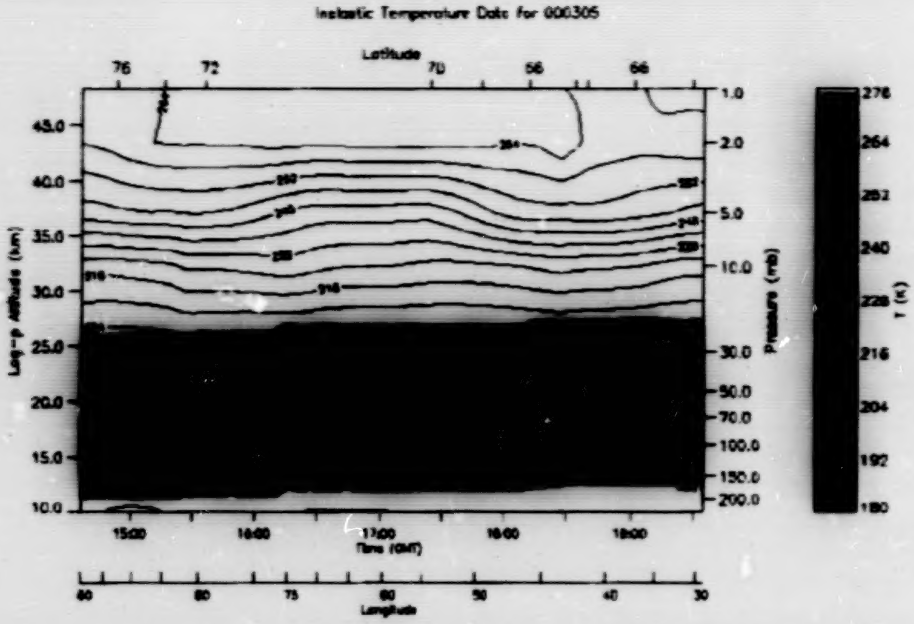


Figure 16. March 5, 2000 temperature retrieved from Raman scattered returns. The black anomalously cold regions have been removed.

Ozone as a function of altitude is also retrieved from the lidar returns, using a differential absorption (DIAL) technique. The 308 radiation is absorbed by ozone and the 355 radiation is used as the atmospheric reference. Figure 17 shows ozone measured above the aircraft along the flight track from Dryden Research Center to Kiruna, Sweden, on February 27, 2000. The transit across the vortex edge can be seen at approximately 74N. Data from these types of measurements within the Arctic vortex were used to calculate the ozone loss rate between mid-January and mid-March. This loss rate, shown in Figure 18, with a maximum loss at about 460 K, amounted to absolute losses in ozone up to 65% at this altitude. In the Antarctic, total ozone loss at some altitudes is observed. From the AROTEL measurements during the SOLVE campaign, we observed that this was a very cold winter and that PSCs, which process the air and initiate the chemistry that leads to the springtime ozone loss, were ubiquitous throughout the Arctic vortex.

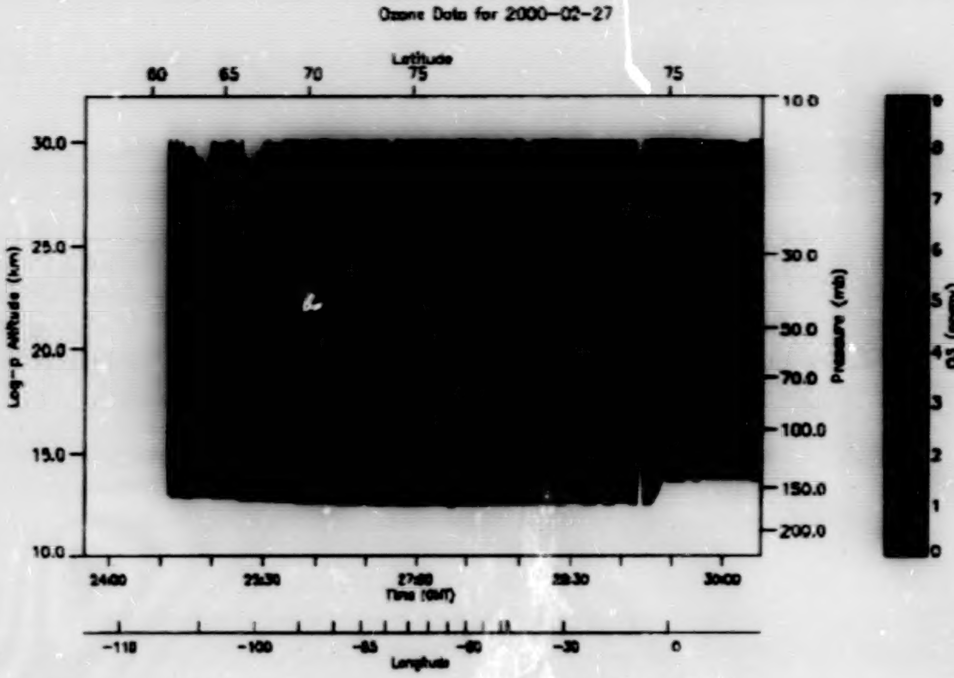


Figure 17. Ozone above the aircraft during the transit flight of January 27, 2000. The vortex edge is very well-defined.

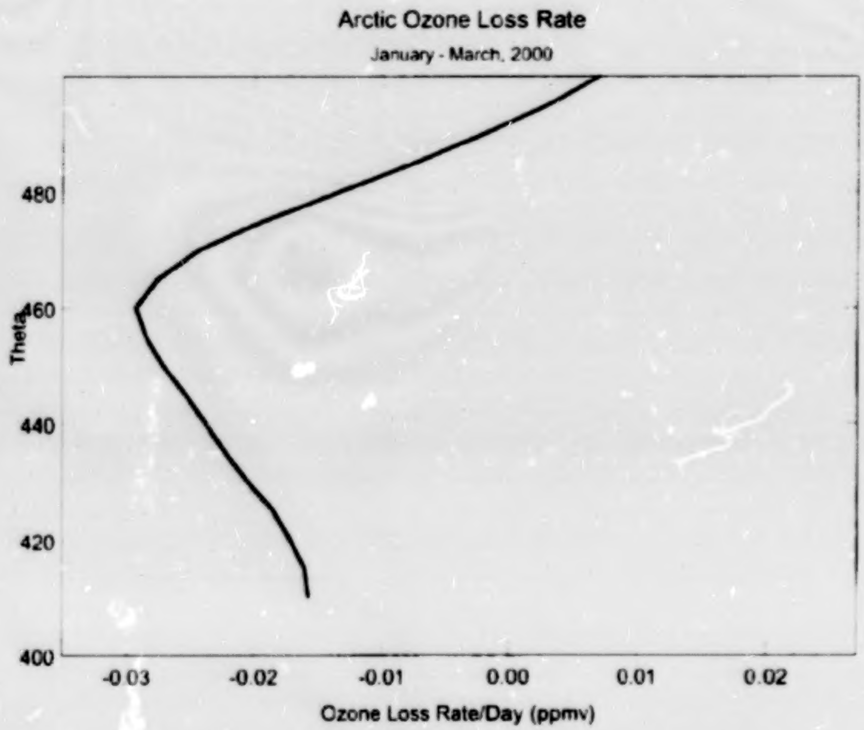


Figure 18. Plot of the ozone loss rate from mid-January to mid-March, 2000, as a function of potential temperature.

Thomas J. McGee, Code 916 (Thomas.J.McGee.1@gsfc.nasa.gov)

Data Analysis

Aerosol Studies

<u>*Operational Use of MODIS/Terra Data for Monitoring Fires in Montana and Idaho*</u>

We used images from MODIS and MOPITT to gather information on wildfires in Montana and Idaho. In fact, during the fires of August 2000, we were able to deliver images to the U.S. Forest Service within 24 hours of real time.

Little snow fell across North America in the winter of 1999-2000. Figure 19, a MODIS 8-day composite from March 512, shows much less snow cover than the 30-year averages for February (yellow line) and March (red line). The lack of snow contributed to near-record low water levels in the Great Lakes. Low water levels and dry soil made conditions ripe for an active wildfire season in the west and mid-west. The literature suggests that signature outgoing longwave radiation (OLR) anomalies precede drought events in North America by about 10 days. The CERES instrument aboard TRMM measured low OLR values off the west coast and high values over the Gulf of Mexico and southeastern U.S. (not shown).

Figure 19, MODIS 8-day composite from March 512, showing much less snow cover than the 30-year averages for February (yellow line) and March (red line).

As has happened in the wake of 16 of the last 19 La Niña events, a large anti-cyclone formed over the central United States, effectively blocking the usual flow of water vapor from the Gulf of Mexico into the region. MODIS data acquired on April 17, 2000, confirms this effect (not shown). Drought conditions worsened and the region became increasingly susceptible to wildfires.

Disaster struck the Bitterroot Valley region of Montana in early August. A wildfire ignited and spread rapidly, spilling over into Idaho and consuming millions of acres over the next 5 weeks. The true-color image below was acquired on August 5 by MISR (Figure 20). On August 29, President Clinton declared parts of Montana and Idaho as disaster areas due to the extensive fire damage.

Figure 20. True color image of Idaho acquired on August 5 by MISR on the Terra spacecraft showing smoke from the wild fires.

On the same day, Terra Project Scientist Yoram Kaufman asked the MODIS and Terra Rapid Response teams to begin providing MODIS data operationally to the U.S. Forest Service to aid in the Service's efforts to contain and extinguish the fires. On August 30, the MODIS Team produced a true-color image over Montana and Idaho (Figure 21) that showed the smoke and burn scars, along with the locations of actively burning portions of the wildfires, as observed by MODIS on August 23. At that time, it took the Rapid Response team a week or more to turn around MODIS images.

Figure 21. Terra MODIS true-color image of fires over Montana and Idaho on August 23 showing the smoke and burn scars, along with the locations of actively burning portions of the wildfires, image produced on August 30. The red dots are saturated pixels where burning is taking place.

The goal in this exercise was to achieve 24-hour turnaround. On August 31, we succeeded in turning around these MODIS images of Idaho acquired on August 30 (Figure 22).

Figure 22. MODIS color composite image of fires in Idaho taken August 30, and processed on August 31 by the Terra Rapid Response team aiding the U.S. Forest Service.

The Terra satellite has also demonstrated some of its potential for new, synergistic approaches to studying Earth events using multiple sensors. For instance, this MOPITT image (Figure 23) shows the levels of carbon monoxide generated by the fires during the period during August 22-27.

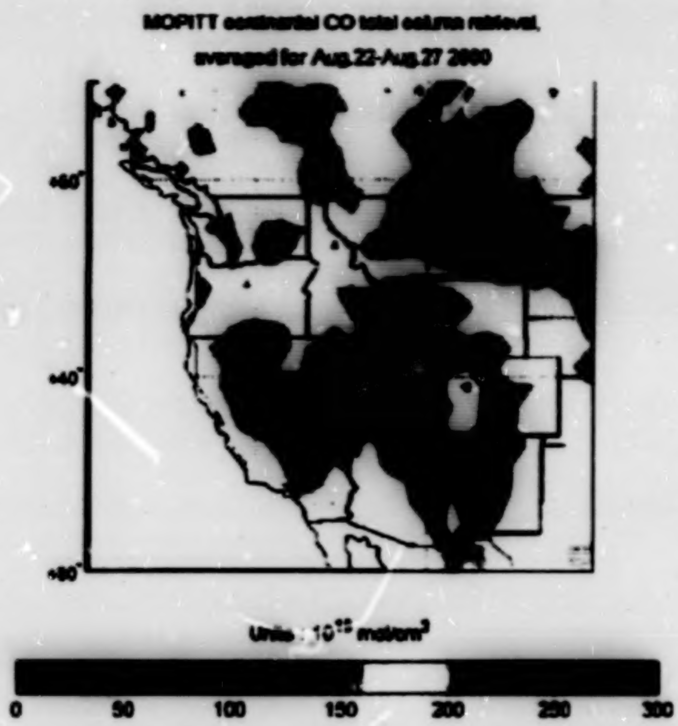


Figure 23. MOPITT image showing the levels of carbon monoxide generated by the fires during August 22-27.

The MODIS images, below, demonstrate MODIS' superior sensitivity to fire intensity as compared to AVHRR (Figure 24). Because MODIS fire channels have a higher saturation threshold, they provide a better gauge of where the hottest parts of the fire are located. In these images, color is a proxy for temperature.

Figure 24. MODIS images in channels 20 and 21 showing sensitivity to fire intensity.

This image (Figure 25) shows the Clear Creek fire in Idaho on the morning of August 30, 2000, as seen by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The image combines a color composite of near-infrared, red, and green light at 15-meter (49-foot) resolution with thermal infrared data at 90-meter (295-foot) resolution.

Figure 25. ASTER image of the Clear Creek fire in Idaho on August 30 combining near infrared, red, and green light at 15 m resolution with thermal infrared at 90 m resolution.

Yoram Kaufman and David Herring, Code 913 (Yoram.J.Kaufman.1@gsfc.nasa.gov, David.D.Herring.1@gsfc.nasa.gov)

Smoke Aerosol from Biomass Burning in Mexico, Hygroscopic Smoke Optical Model

We used data from Mexico, South America, and Africa to characterize regional variations in smoke generated by biomass burning.

In 1998, an especially dry spring created an intense fire situation in the tropical areas of southern Mexico and Central America. Fires burned out of control for weeks and covered the region with thick smoke. In May, wind carried the smoke northward into the United States, where it was observed as far north as Wisconsin. The event generated much attention within the United States, but was otherwise typical. In the tropics, biomass burning occurs globally and produces vast quantities of smoke that can cover regions as large as half a continent.

The smoke particles, called smoke aerosol, play a role in the Earth's energy balance by directly reflecting solar radiation back to space and by altering cloud properties that indirectly change cloud reflectance and rain production efficiency. We still do not understand exactly how the smoke aerosol affects the energy balance and changes climate. Much of our ignorance arises from a lack of understanding of the physical and optical properties of the particles themselves. Do

these properties vary by geographic region? If so, is there a physical model that can describe the variation?

We analyzed the data acquired from the 1998 Mexico event in conjunction with chemical data collected in the United States and Sun/sky radiometer data collected in North and South America and Africa. The combination of these data sets results in a simple physical model that explains the regional variation in smoke properties as a function of particle water vapor absorption and variability in light absorbing carbon content.

Data from the Interagency Monitoring of Protected Visual Environments (IMPROVE), a network of aerosol measuring systems distributed across the United States, provides the chemical composition of the aerosol. We use the IMPROVE observations at Big Bend National Park (BBNP), located along the Mexican border in south Texas, to identify biomass burning aerosol with a chemical indicator. The identified smoke aerosol shows a higher sulfate component at BBNP than at other stations measuring biomass burning aerosol in the United States and in South America. The larger fraction of sulfate, a byproduct of industry, is not surprising, as the smoke plume from the tropical regions passed over sources from major industrial regions and power plants in central and northern Mexico. Sulfates are strongly hygroscopic substances meaning that they readily absorb water from their environment. A larger fraction of sulfate in an aerosol particle suggests that these particles will be more strongly hygroscopic than similar particles with less sulfate.

Because the Mexican smoke particles have a larger hygroscopic component than smoke from other regions, we expect these particles to absorb more water and thus be larger, with a larger single-scattering albedo (ω_o). Single-scattering albedo is the ratio between a particle's scattering and extinction coefficients. Larger ω_o, therefore, indicates more scattering and less absorption. A particle grows in size as it takes in water and simultaneously dilutes the light absorption materials of the particle. The AErosol RObotic NETwork (AERONET), a global network of Sun/sky radiometers, provides size and optical properties of smoke from Mexico, South America, and Africa. AERONET data show that, indeed, Mexican smoke consists of larger particles exhibiting less light absorption (larger ω_o) than similar particles from other tropical biomass burning regions. We have established a consistent physical model that shows that water up-take alone can explain the geographical variation in the particle size (Figure 26a). However, water alone cannot account for the variation in light absorption (variation in ω_o). Variations in light absorbing carbon (LAC) are also necessary. As Figure 26b shows, the global variation in particle light absorption (single scattering albedo – ω_o) can be explained by a physical model that combines a hygroscopic model with the variations of LAC measured in different locations.

Our hygroscopic smoke aerosol model demonstrates that the particle size and optical properties are not independent, but vary in tandem with variations in the particle's readiness to absorb water and with variations in light absorbing carbon amounts. The results imply that these broad, interconnected variations in smoke aerosol properties are important to both the accurate assessment of the global effects of biomass burning aerosols on climate and the remote sensing of such aerosols from space.

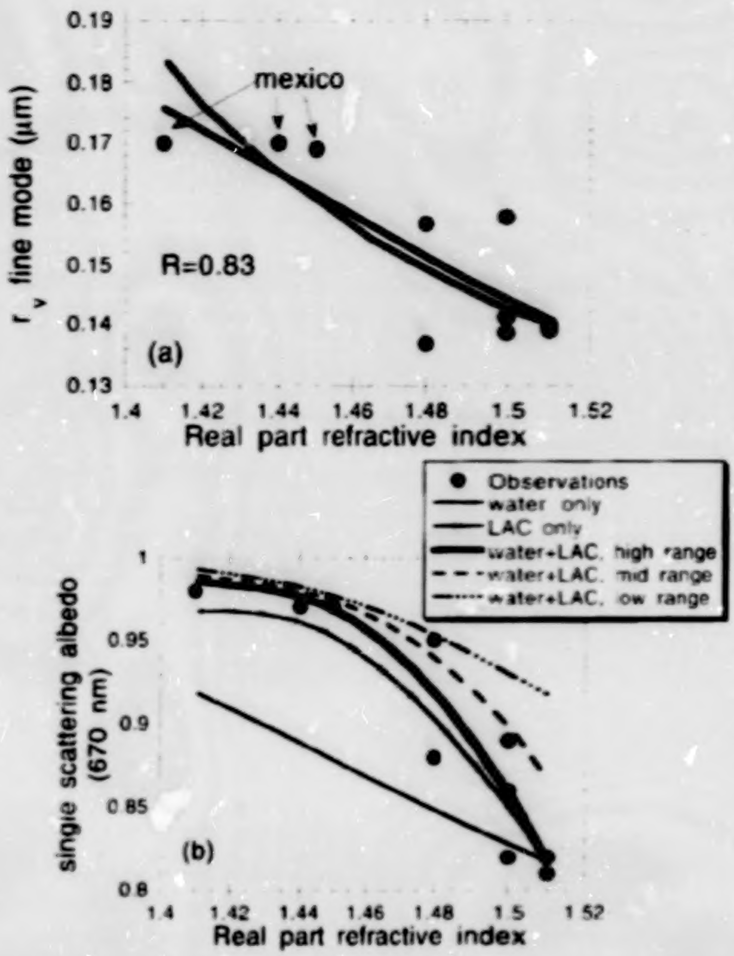


Figure 26. The figure shows smoke particle size (r_v), top (26a), and single-scattering albedo at 670 nm (ω_o), bottom (26b), as functions of the real part of the refractive index, n_r, for several stations in Mexico, Africa, and South America. The data represents mean conditions for optical thickness at 670 nm near 0.50. The points representing Mexican aerosols are identified in the top panel. In the top panel (26a) the black line is the best fit through the data points with the correlation coefficient given. The red line represents a particle size growth model dependent only on water uptake. In the bottom panel (26b) the red line represents the same water only model of the top panel. The orange line represents a dry model with varying light absorbing carbon (LAC). The other lines represent wet models with varying LAC as observed in smoke-affected aerosols from Africa, South America, and the Mexican event.

Lorraine A. Remer, Code 913 (Lorraine.A.Remer.1@gsfc.nasa.gov)

Clouds and Precipitation

Accuracy of TRMM Monthly Rainfall Maps

One of the primary data products of the Tropical Rainfall Measuring Mission (TRMM) satellite is monthly maps of rainfall. For instance, Figure 27 shows gridded TRMM estimates of the rainfall for the month of January 1998 on a 2.5° grid over the Pacific Ocean within 10° of the equator. In order to use such maps for such quantitative work as comparisons with seasonal forecast models or studies of the global water balance, we need some measure of the accuracy of the rainfall estimates in each grid box.

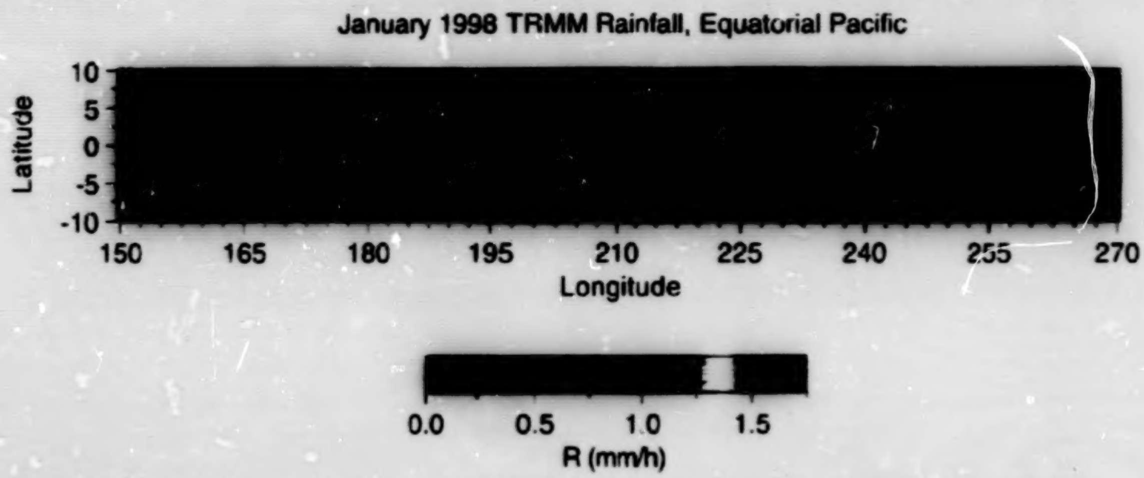


Figure 27. A gridded map of monthly rainfall typical of those produced from TRMM rain data. Enhanced amounts of rainfall can be seen in the central Pacific typical of the large El Niño episode in progress at that time.

The TRMM estimates of monthly rainfall in each grid box can be in error for two reasons: (1) Errors occur in trying to estimate rainfall with remote-sensing methods based on microwave radiation from the precipitating systems, and (2) the satellite cannot view the grid box continuously, since the satellite views grid boxes only about once per day on average. We have developed a method for estimating the root-mean-square (rms) "random" component of this error, denoted by σ_E.

The method predicts that the rms error of satellite averages should be proportional to the variability of area-averaged rain rate, which can be directly estimated from the satellite data. The method was tested using rainfall estimates obtained from two orbiting Defense Meteorological Satellite Program (DMSP) satellites carrying microwave instruments, the Special Sensor Microwave/Imagers (SSM/I), similar to those on TRMM. By comparing the two SSM/I estimates of rainfall for the same month and grid box, we can estimate the random error σ_E in monthly averages of rainfall from the satellites. Estimates of mean squared errors σ_E^2 are plotted versus a measure of the variability in grid-box averages of rain rate, σ_A^2, in Figure 28. They are indeed proportional, as predicted. We can estimate the proportionality constant by knowing the frequency of visits by the satellite and the time correlation of area-averaged rainfall. The proportionality constant is not sensitively dependent on the time correlations of rainfall. Thus, we can make reasonably accurate estimates of the proportionality constant from satellite data alone. It is therefore possible to provide estimates of the amount of random error present for each grid-box average in maps like that in Figure 27. The method is described in a paper to appear in the *J. Appl. Meteor.* (Bell et al. 2001).

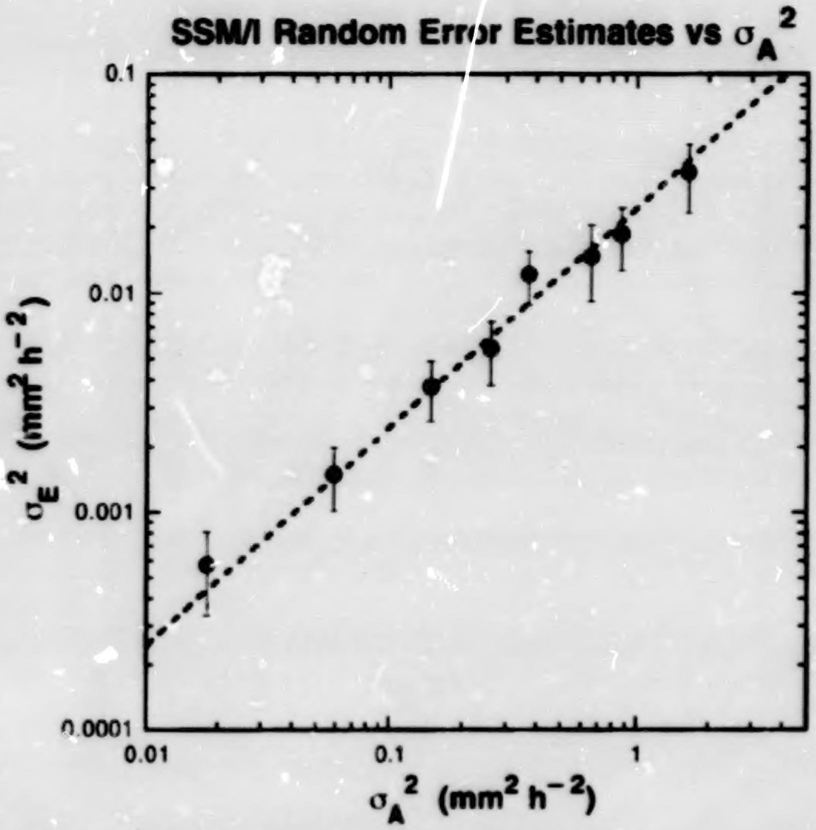


Figure 28. Estimates of the mean squared random error in monthly average rainfall obtained from microwave instruments aboard either of two Defense Department meteorological satellites, plotted versus the variance of area-averaged rain rate for 2.5° × 2.5° grid boxes. Their proportionality is predicted by a theory that allows us to estimate the amount of random error in gridded rainfall estimates such as those in Figure 27.

Thomas L. Bell, Code 913 (Thomas.L.Bell.1@gsfc.nasa.gov)

Effect of Radiative Cooling on the Relation between Cloud and Sea Surface Temperature

We have shown that one of the important processes in determining cloudiness over the pacific warm pool is radiative cooling in the surrounding subsiding atmosphere over the cold pool. Water vapor and clouds play an important role in maintaining the earth climate. Water vapor is recognized as a positive climate feedback process. This recognition is supported by observations that the area-mean greenhouse trapping of the clear-sky in the tropics generally increases from cold to warm sea surface temperature (SST). However, water vapor distribution is tightly coupled to clouds. Recent studies revealed that the change in the area of dry and subsiding regions relative to moist and convective regions determines the net greenhouse trapping. The local and remote processes determining the relative area are key climate issues.

In our work, we first examined the SST-cloud relationship in the tropical deep-convective regime and the surrounding subsidence regime in the Goddard Cumulus Ensemble model. Figure 29 schematically summarizes the overall model response in different low-boundary forcing conditions. Here the low-boundary forcing is expresses as SST contrast between the warm pool and cold pool (dSST). From weak to strong dSST, the area of downward motion increases while the magnitude of downward motion remains the same. This is because the strength of subsidence is limited by radiative cooling, which has a small variability. As a result, the area of radiatively

driven subsidence expands to produce an enhanced mass exchange between the warm pool and cold pool in response to enhanced dSST. The accompanying changes over the warm pool are a reduced convective area with an enhanced mean upward motion and rainrate.

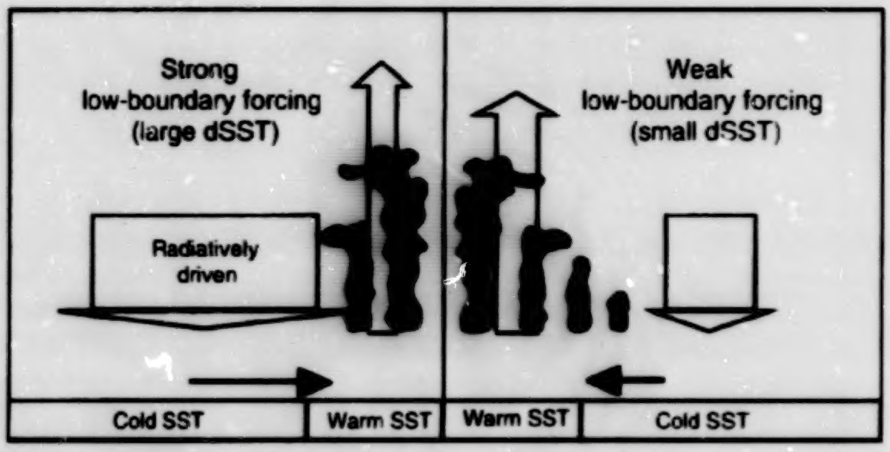


Figure 29. Schematic summary of tropical circulation and clouds in strong & weak low-boundary forcing regimes.

We then sought supporting evidence for the above model results by analyzing high cloud amount (A_{HC}) and vertical p-velocity (ω) as functions of SST. A_{HC} is derived from the International Satellite Cloud Climatology Project (ISCCP D2 data averaged to 2.5°x2.5° longitude-latitude spatial resolution and monthly time scale for the period of July 1983 - August 1994). Vertical p-velocity (ω) is derived from the NCEP reanalysis. The warm pool and cold pool within the tropical Pacific (20°S-20°N, 130°E-110°W) are separated by an isotherm so that the area of warm pool is 25% of the analysis domain. Mean cloudiness over the warm pool and cold pool are plotted in Figure 30a as a function of the corresponding dSST.

What did our analysis show? Over the warm pool, A_{HC} appears to be positively correlated with dSST for the weak low-boundary forcing condition (dSST<2.6°C). This correlation is associated with the increased ascending (descending) motion over the warm (cold) pool with enhanced dSST as shown by the $-\omega$ at 500 hPa level in Figure 30b. The correlation is reversed for the strong low-boundary forcing condition (dSST>2.6°C). The results suggest that the expanded subsidence area acts against increased clouds by enhanced upward mass flux over the warm pool. The subsidence produces less cloudy (more clear) regions over the warm pool when dSST is stronger than normal. Over the cold pool, A_{HC} and $-\omega$ are negatively correlated with dSST as is expected from the expansion of subsidence area with increasing dSST discussed above.

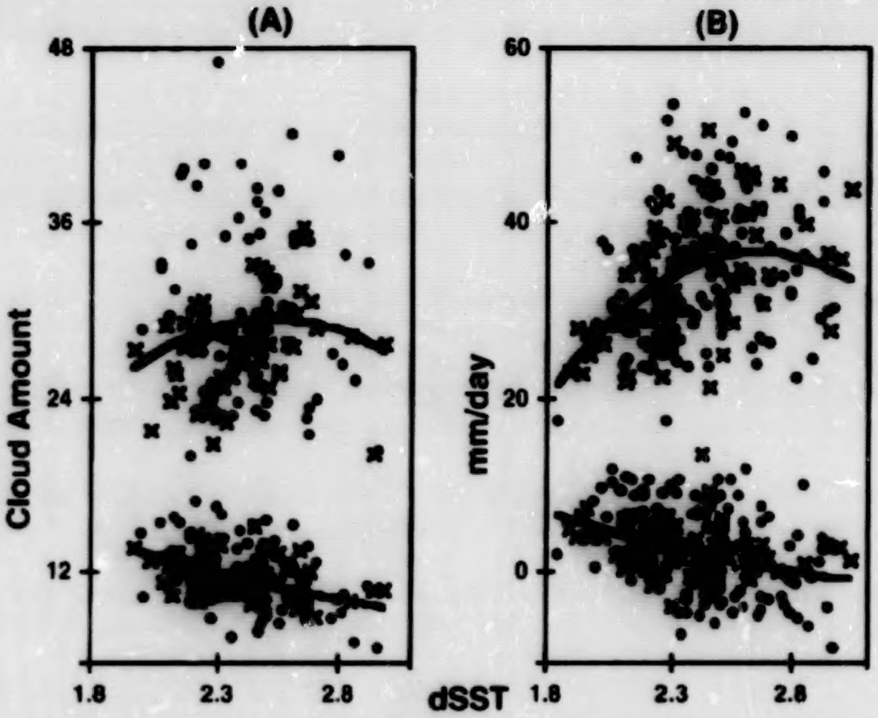


Figure 30. Scatter plot of A_{HC} (A), and $-\omega$(500 hPa) (B) over the warm pool (upper) and cold pool (lower) as a function of dSST. o, x, and • correspond to the three categories of ω at 500 hPa: $(\omega-\omega_m)<-2$ mbday^{-1} (open circles), $|\omega-\omega_m|<2$ mbday^{-1} (crosses), and $(\omega-\omega_m)>2$ mbday^{-1} (close circles), where ω_m is the time mean ω.

The current analysis indicates that radiative cooling in the subsidence regime plays an important role in regulating SST-cloud interaction. The SST-cloud relation is crucial for understanding radiation-climate feedbacks in global climate change either induced naturally or anthropogenically.

Chung-Hsiung Sui, Code 913 (Chung-Hsiung.Sui.1@gsfc.nasa.gov)

The Use of Vegetation for Estimating Broken-Cloud Optical Properties from Surface Radiance Measurements

A key to predicting climate change is to observe and understand the global distribution of clouds and their physical properties such as optical thickness and droplet size. Since clouds change rapidly over short time and space intervals, they are difficult to simulate in computer models. But, it is essential that global climate models predict realistic spatial and temporal distribution of cloud optical depth. The best way to verify these distributions is to infer optical depth from global coverage satellite data. However, satellite methods have many sources of uncertainty; thus, independent and reliable ground-based estimates are essential for validation.

Although clouds vary substantially horizontally, all ground-based retrievals of cloud properties assume that clouds vary only vertically, ignoring not only horizontal in-cloud structure but also broken cloudiness. This assumption leads to misinterpretation of cloud properties and often makes their remote sensing impossible.

We developed a new technique that retrieves cloud optical thickness for broken clouds above green vegetation from surface measurements of zenith radiance in the visible (VIS) and near-IR (NIR) spectral regions. The idea of the method is simple. Since green vegetation reflects 40-50% of incoming radiation in the NIR and only 5-10% in the VIS region, ground measurements under thin clouds have little spectral contrast between VIS and NIR, while thick clouds reflect much more of the surface-reflected radiation in the NIR than in VIS. Based on this idea, we proposed to use a combination of measurements (spectral indices) in VIS and NIR to estimate cloud optical thickness.

Spectral indices that exploit this contrast are quite popular in the land-surface remote-sensing community. Among more than a dozen indices, the most widely used is the Normalized Difference Vegetation Index (NDVI) proposed by Jim Tucker from GSFC in 1979. By analogy with NDVI, we defined the Normalized Difference Cloud Index (NDCI) as a ratio between the difference and the sum of two radiances measured for two narrow spectral bands in VIS and NIR. NDCI uses the green vegetation as a powerful reflector illuminating horizontally inhomogeneous clouds from below. This provides the extra information needed to largely remove the ambiguity in measured radiance caused by radiative effects of the three-dimensional cloud structure. As a result, in contrast to conventional methods that yield almost entirely invalid results when clouds are broken, our new method gives a reliable estimate of the distribution of optical depth even for broken clouds.

For proof-of-concept measurements, we used downwelling flux at the surface measured by the Shortwave Spectrometer (SWS) at the Atmospheric Radiation Measurement (ARM) site in Oklahoma. SWS measures solar spectral flux between 0.35 and 2.5 µm, continuously, with spectral resolution 1 nm and temporal resolution of less than 1 minute. In addition to SWS, we also used the Microwave Water Radiometer (MWR) that measures column-integrated liquid water (LWP). Figure 31 shows a ratio between the difference and the sum of two downwelling fluxes (per unit incident flux) measured by SWS at 0.67 and 0.87 µm on April 29, 1998. Single and multilayered boundary layer clouds were reported that day. We plotted the ratio (flux NDCI) on the same plot as cloud LWP averaged over 1 minute. Clearly, flux NDCI is highly correlated with LWP. It is expected, though, that the correlation between NDCI and LWP will be even better if radiances are used instead of fluxes.

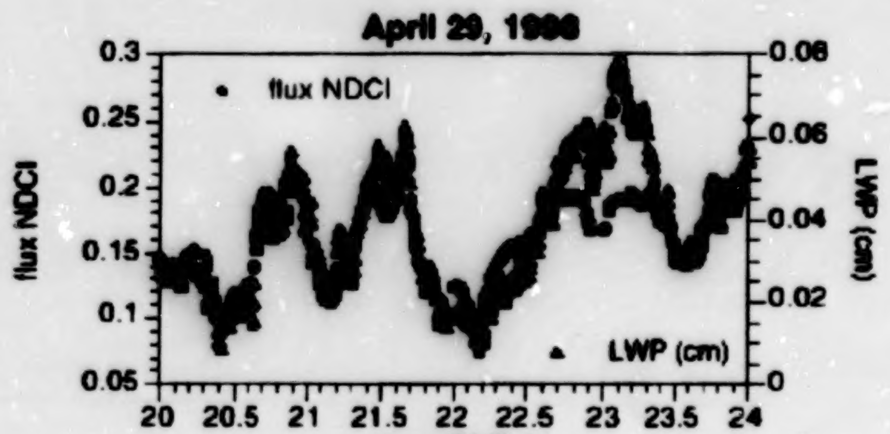


Figure 31. Flux NDCI and cloud LWP measured at the ARM site in Oklahoma and averaged in 1-minute increments. Note a poor correlation for about 40 minutes from 22.7 to 23.3 h. The reason for the poor correlation is not yet understood.

One of the proposed applications of the NDCI is developing a new "cloud mode" for the AERONET (AErosol RObotic NETwork) a ground based aerosol monitoring network that consists of identical multi-channel radiometers. As a product, the developed technique will yield the distribution of cloud optical depth at each AERONET site that is surrounded by green vegetation (more than 100 around the world). Global climate models can use the observations to produce realistic spatial and temporal distribution of cloud optical depth. The data will be added to the publicly available AERONET database.

The first preliminary results were reported in the Geophysical Research Letters: Marshak, A., Y. Knyazikhin, A. Davis, W. Wiscombe, and P. Pilewskie, 2000. Cloud-vegetation interaction: use of Normalized Difference Cloud Index for estimation of cloud optical thickness. Geophys. Res. Let., 27, 1695-1698.

Alexander Marshak, Code 913 (Alexander.Marshak.1@gsfc.nasa.gov)

Effects of Clouds on the Solar Heating of the Atmosphere in the Tropical Western Pacific

Do clouds enhance the solar heating of the atmosphere? Some studies using observed data have shown that clouds enhance the solar heating of atmosphere significantly, whereas radiative transfer models predict no excess heating due to the presence of clouds. Resolving this issue is very important because reliable climate model simulations and satellite remote sensing of the atmosphere depend crucially on accurate radiative transfer calculations. Nevertheless, this issue is still largely unresolved primarily due to the lack of comprehensive data sets for the radiation both at the top of the atmosphere and at the surface. To estimate the effect of clouds on the solar heating of the atmosphere, we need information on the clear- and cloudy-sky net downward solar fluxes at the top of the atmosphere and at the surface. Laboratory scientists have developed methodology to derive the surface solar radiation from measurements by the Japanese Geostationary Meteorological Satellite (GMS), which views the tropical western Pacific. The satellite-retrieved surface radiation is then combined with the CERES-retrieved top-of-the-atmosphere radiation to estimate the effect of clouds on atmospheric solar heating.

Table V shows that the magnitudes of atmospheric solar heating, Q, vary only slightly between the tropical western Pacific and South China Sea. It is ~102 W m-2 for the all-sky solar heating and ~80 W m-2 for the clear-sky solar heating. Thus, clouds enhance the atmospheric solar heating significantly by ~22 W m-2.

Table V. Solar Radiation Budget of the period January-August 1998.

	All-Sky	Clear-Sky	CRF
S_t	315	354	-39
S_s	215	276	-61
Q	100	78	22
S_t	336	371	-35
S_s	233	289	-56
Q	103	82	21

CRF : Cloud radiative forcing
S_t : Net downward solar flux at top of atmosphere
S_s : Net downward solar flux at surface
Q : Atmospheric solar heating
Units: W m^{-2}

Ming-Dah Chou, Code 913 (Ming-Dah.Chou.1@gsfc.nasa.gov)

Climate Variability and Climate Change

A Multiyear Data Set of SSM/I-Derived Global Ocean Surface Turbulent Fluxes

The turbulent fluxes of momentum (or wind stress), latent heat of evaporation, and sensible heat at the global ocean surface are required for driving ocean models and validating coupled ocean-atmosphere global models. Laboratory scientists have developed methodology to retrieve a 7.5-year (July 1987-December 1994) data set of daily surface turbulent fluxes over global oceans from the Special Sensor Microwave/Imager (SSM/I) data and other data (Chou et al. 1995, 1997).

Accuracy of the retrieved surface air humidity (for computing latent heat fluxes) has been validated against the collocated radiosonde observations over the global oceans. The retrieved wind stress and latent heat flux show useful accuracy as verified against the research quality measurements of ship and buoy in the western equatorial Pacific (Chou et al. 1997, 2000). The 1988-94 seasonal-mean wind stress and latent heat flux show reasonable patterns related to seasonal variations of the atmospheric general circulation. The patterns of 1990-93 annual-mean turbulent fluxes and relevant parameters are generally in good agreement with those of a global analyzed flux data set that based on COADS (comprehensive ocean-atmosphere data set) with wind speed corrections. The retrieved wind speed is generally within ± 1 m s^{-1} of the modified COADS winds, but is weaker by ~1-2 m s^{-1} in the northern extratropical oceans. This discrepancy may be due mainly to higher modified COADS winds, which result from an underestimation of anemometer heights of ships. Compared to the COADS-based fields, the retrieved latent heat flux and sea-air humidity differences are generally larger, with significant differences in the trade wind zones and the oceans south of 40°S (up to ~40-60 W m^{-2} and ~ 1-1.5 g kg^{-1}). The discrepancy is believed to be caused by higher COADS-based surface air humidity arising from the overestimation of dew point temperatures and from the extrapolation of observed high humidity southward into data-void regions south of 40°S. The retrieved sensible heat flux is generally within ± 5 W m^{-2} of the COADS-based, except for some areas in the extratropical oceans, where the differences in wind speed have large impact on the difference in sensible heat flux. The data set of SSM/I-derived turbulent fluxes is useful for climate studies, forcing of ocean models, and validation of coupled ocean-atmosphere global models.

We have also combined the turbulent fluxes and the surface radiative fluxes retrieved from Japan's GMS data to study temporal and spatial variability of surface heat budgets and their relationship to sea surface temperature in the Pacific warm pool during the TOGA COARE (Chou et al. 2000). The impacts of Madden-Julian oscillations (intra-seasonal oscillations) and westerly wind bursts on the surface heat budget and sea surface temperature from November 1992 to February 1993 were included.

Shu-Hsien Chou, Code 912 (Shu-Hsien.Chou.1@gsfc.nasa.gov)

Planetary Sciences

Galileo Mission Highlights

Laboratory scientists were able to obtain for the first time an accurate measurement of the $^{14}N/^{15}N$ ratio on Jupiter using data from the Galileo Probe Mass Spectrometer (GPMS). The probe entered Jupiter's atmosphere in December 1995. These new results give the best estimate to date of the protosolar $^{14}N/^{15}N$ ratio. The measurement is important because the reservoirs of nitrogen in the solar system are poorly constrained and for lack of a better value the terrestrial atmospheric N_2 has commonly been adopted as the solar system value. This data can now provide constraints, for example, on models that study such physical processes as atmospheric escape. Such processes might produce substantially different values for this atmospheric ratio on the terrestrial planets Venus, Earth, and Mars.

Nitrogen isotope measurements are very difficult to obtain from the singly charged ratio of $^{14}NH_3^+/^{15}NH_3^+$ at 17 and 18 amu because the contribution of water to 18 amu cannot be independently constrained. The spectral overlap is illustrated in Figure 32. Thus the new measurement comes from a study of the doubly ionized ammonia (NH_3^{++}) signal throughout the course of the probe's descent into the Jovian atmosphere.

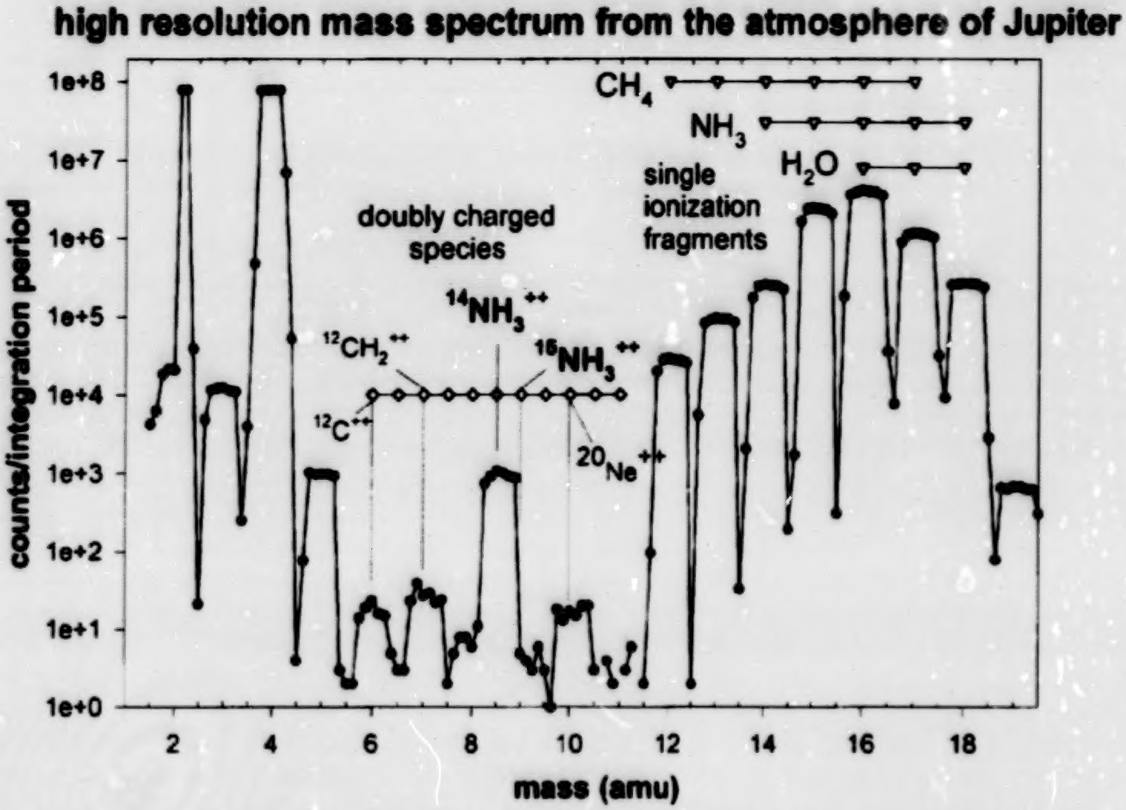


Figure 32. A 1/8 amu resolution mass scan obtained near the 17 bar pressure region of Jupiter's atmosphere shows the doubly charged species that are produced by electron impact ionization in the source of the mass spectrometer. The ratio of the doubly charged ammonia signal at 8.5 and 9.0 amu allows the Jovian and the protosolar $^{14}N/^{15}N$ ratio to be obtained. This ratio is considerably larger than the terrestrial ratio.

The isotope, $^{15}NH_3^{++}$ produces a signal at 9 amu while $^{14}NH_3^{++}$ produces a signal at 8.5 amu. The focus of the predetermined measurement sequence was on singly charged species and not on these doubly charged species. Hence, only one 8.5 amu measurement appears in this data set (at data step 5696) at a pressure of 17.2 bar. Nevertheless, we can predict the value of the 8.5 amu signal at any point in the probe descent. We do this by determining the ammonia fractional contribution to 17 amu and using the NH_3^{+}/NH_3^{++} ratio established from both the flight data itself and associated studies on the engineering unit presently operational in our laboratory. In one measurement period, the GPMS analyzed an enriched gas sample obtained from the Jovian atmosphere between 0.8 and 2.8 bar. The spectra from that sample give strong signals at 9 amu. It is from these measurement that we establish our best value of this ratio.

The Jovian and protosolar $^{14}N/^{15}N$ ratio established by these measurements is 430 with uncertainties of only a few percent. This ratio is consistent with several other recent observations such as the ISO (Infrared Space Observatory) measurement of Jovian ammonia and a very recent detailed study of solar wind implanted nitrogen in lunar samples. Our present result greatly reduces the uncertainty remaining from these studies. The ratio we measure at Jupiter is also consistent with our present understanding of the $^{14}N/^{15}N$ ratio in N_2 in the interstellar medium. The GPMS isotope ratio of 430 can be compared with the corresponding terrestrial value of this ratio in atmospheric N_2 of 273. It is likely that the source material for the Earth's atmosphere,

including external contributions from primitive bodies such as comets, did not reflect this average value. In addition, fractionation of nitrogen over the lifetime of the Earth's atmosphere may also contribute to this difference.

Paul R. Mahaffy, Code 915 (Paul.R.Mahaffy.1@gsfc.nasa.gov)

Modeling

Data Assimilation

Improving Four-Dimensional Global Data Sets and Short-Range Forecasts Using TRMM and SSM/I-Derived Rainfall and Moisture Observations

Laboratory for Atmospheres research has shown that assimilating rainfall and moisture observations derived from spaceborne passive microwave sensors in global models can significantly improve the quality of global data sets and short-range forecasts. Specifically, assimilation of rainfall and total precipitable water (TPW) data derived from TRMM Microwave Imager (TMI) and SSM/I improves not only the hydrological cycle but also key climate parameters in the tropics in the GEOS analysis.

Figure 33 shows the results of assimilating 6-hour averaged rainfall and TPW in the GEOS DAS for June 1998. The panels show the improvements on four assimilation fields: tropical precipitation, TPW, outgoing longwave radiation (OLR), and outgoing shortwave radiation (OSR). The monthly-mean spatial biases and error standard deviations are substantially reduced.

The apparent exceptions are biases in the tropical-mean precipitation and OLR. The slightly larger precipitation bias demonstrates that the rainfall assimilation algorithm is more effective in reducing than enhancing precipitation. The apparent increase in the OLR bias reflects the virtual elimination of the negative OLR bias associated with errors in precipitation. Eliminating the negative OLR bias leaves a tropical-mean bias dominated by the positive, but reduced, bias in the rain-free regions.

Overall, rainfall assimilation reduces the state-dependent systematic errors in clouds and radiation in raining regions, while TPW assimilation reduces errors in the moisture field to improve the longwave radiation in clear-sky regions. The OSR errors in the GEOS analysis are dominated by errors in clouds; the improved OSR indicates improved cloud patterns.

The improved analysis also leads to better short-range forecasts in the tropics, as shown in Figure 34. This work illustrates the potential of using space-based rainfall and TPW observations for improving numerical weather prediction and the quality of assimilated global data sets for climate research.

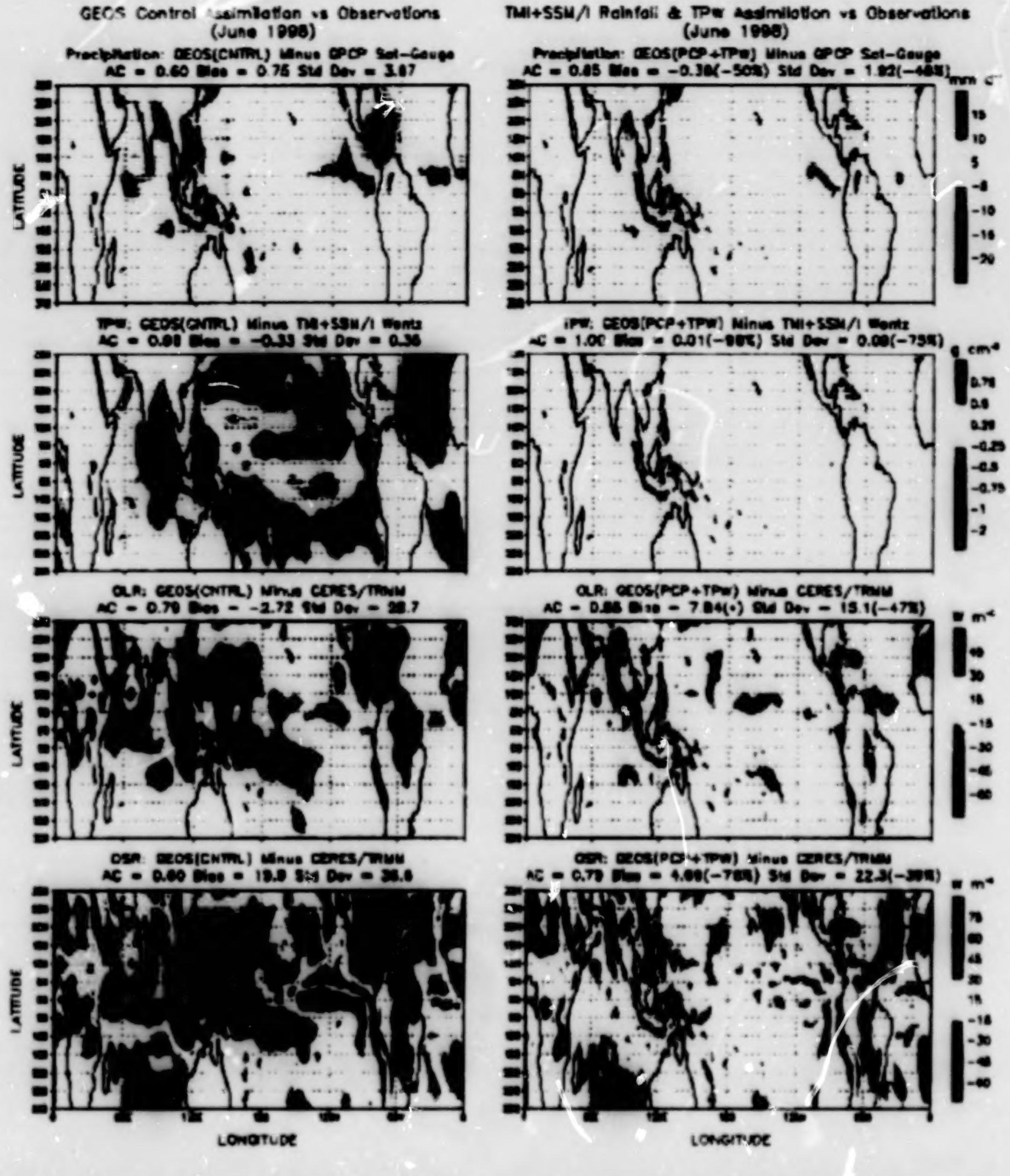


Figure 33. NASA GEOS assimilation results with and without TMI and SSM/I observations for June 1998. Left panels show errors in the monthly-mean tropical precipitation, total precipitable water, outgoing longwave radiation, and outgoing shortwave radiation in the GEOS control assimilation. Right panel shows the impact of assimilating TMI and SSM/I rainfall and TPW observations on these fields. Percentage changes relative to errors in the GEOS control are given in parentheses.

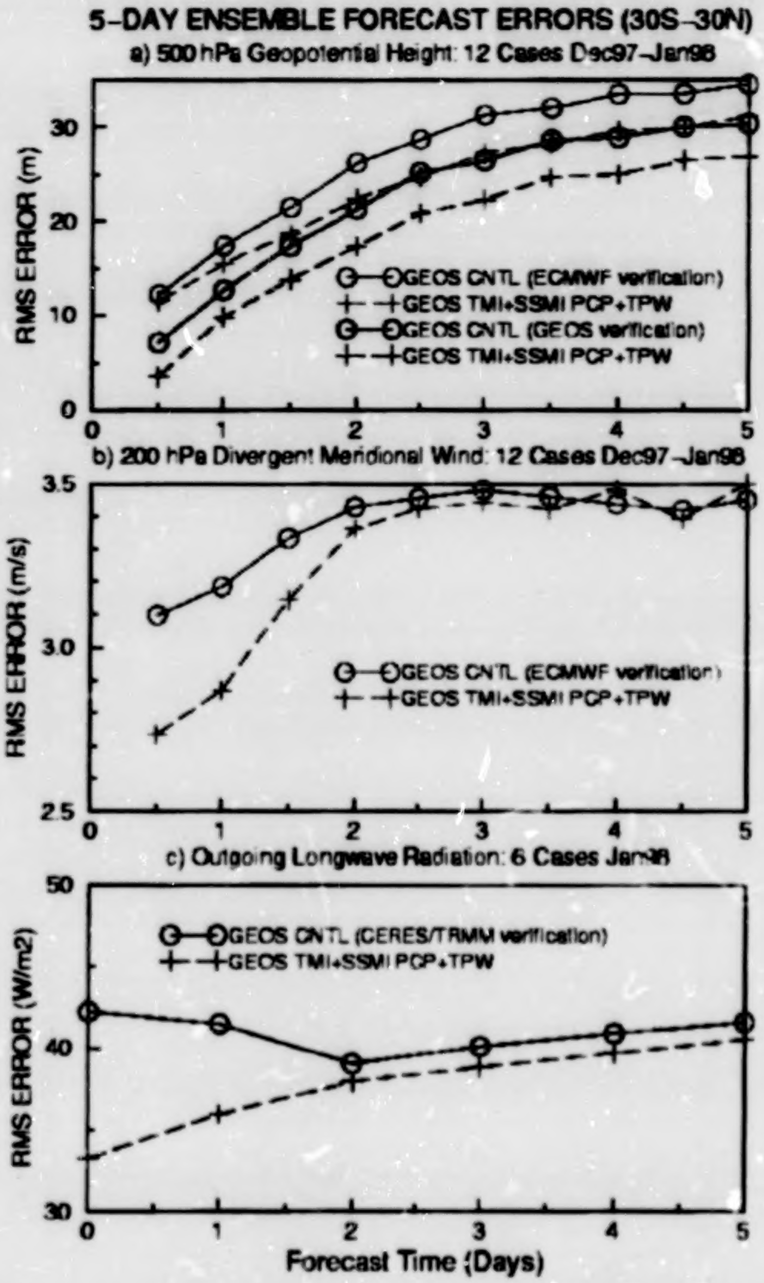


Figure 34. (a) Five-day ensemble forecast rms errors in tropical geopotential height at 500 hPa. Results in green are verified against the ECMWF analysis and results in red are verified against the average of the GEOS control analysis and the TMI and SSM/I rainfall and TPW assimilation. (b) Same as (a) except for the 200 hPa divergent meridional wind verified against the ECMWF analysis. (c) Same as (a) except for the OLR verified against CERES/TRMM observations.

Arthur Hou, Code 910.3 (Arthur.Y.Hou.1@gsfc.nasa.gov)

DAO Supports the SOLVE Mission

An important role for the DAO over the last decade has been supporting NASA's satellite validation missions and aircraft campaigns. The DAO continued this support while participating in the SAGE-III Ozone Loss and Validation Experiment (SOLVE). Several DAO scientists traveled to Kiruna in northern Sweden for several weeks between December 1999 and March 2000. There, they collaborated with the team of meteorologists and experimental physicists and chemists who used NASA's DC-8 and ER-2 aircraft to measure ozone and other important trace gases in and around the polar vortex.

Meteorological analyses and forecasts from the DAO and other centers were used in the field to help plan the flights. Medium-range forecasts were used to assess the prospects of flying inside the polar vortex or along the edge to measure several critically important trace gases and aerosols. One-day forecasts helped fine-tune the flight paths. The flight criteria were to be able to fly through cold regions while avoiding turbulence. Polar stratospheric clouds in these cold regions are sites of substantial chemical processing of air. DAO scientists collaborated with meteorologists from other centers to determine where these conditions were met.

Figure 35 shows a time series of DAO meteorological analyses and forecasts of 50-hPa geopotential height (red bundle of contours between 1962 and 1978gpdm) and temperature (shaded green and blue for values of less than 200K and 195K, respectively). The time (moving from left to right) extends from February 5 through February 10, 2000. The analyses (top row) show the transition from a triangular, cold polar vortex, which had dominated the flow since the latter third of January, to a warmer, elongated polar vortex, associated with a minor stratospheric warming. In the lower stratosphere, forecasting of such transitions is known to be difficult. Here, though, the DAO system captured the change in vortex structure. The 5-day forecast for February 10 shows a slightly large, cold vortex core, failing to capture the full magnitude of the warming event. However, the 4-day and shorter forecasts all show a reasonable structure (right-hand column).

The lessons learned were substantial. The DAO analyses and forecasts proved to be reliable products compared to those of other major centers. These products served as a validation for the GEOS-3 (Terra) system. The forecasts were generally of good quality, with a slight warm bias and a tendency to zonalize the stratospheric flow. The DAO analyses were used in interpreting Solve data, giving important input to chemical-transport models in the Atmospheric Chemistry and Dynamics Branch at GSFC.

DAO will continue to support such field campaigns. The next is Trace-P, a mission to study trace gases and aerosols in the western Pacific region. This mission will take place in the spring of 2001. In November 2001, DAO will support a field campaign based in Darwin, where ground-based (sonde, radar, and lidar) measurements will be used to study the excitation and propagation of internal gravity waves, which propagate from the troposphere to the mesosphere.

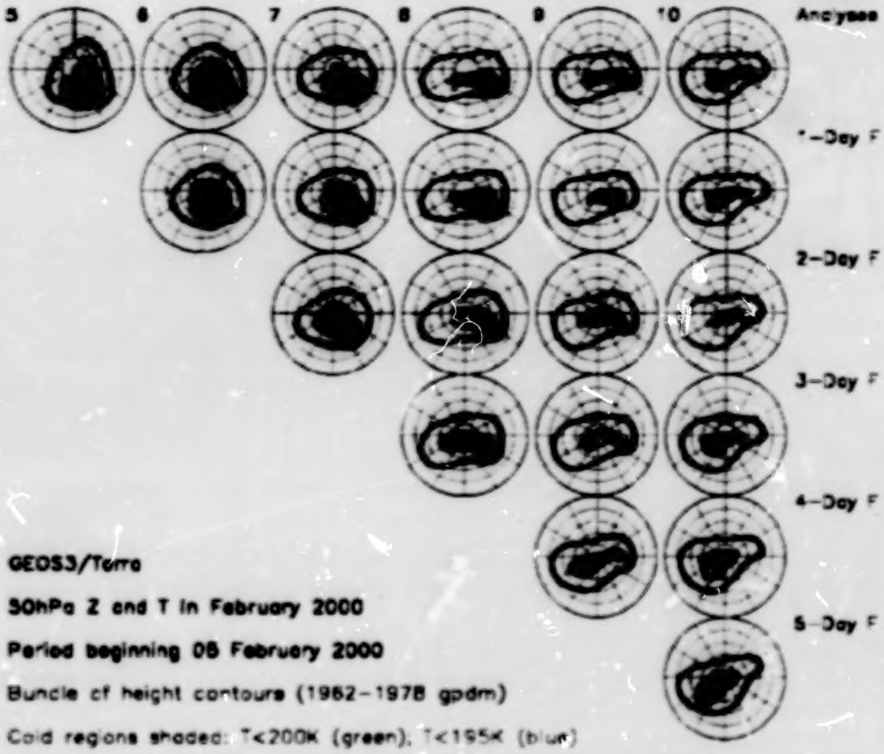


Figure 35. A time series of DAO meteorological analyses and forecasts of 50-hPa geopotential height (red bundle of contours between 1962 and 1978gpdm) and temperature (shaded green and blue for values of less than 200K and 195K, respectively).

Steve Pawson, Code 910.3 (spawson@dao.gsfc.nasa.gov)

The Predictability of Seasonal Means During Northern Summer

It is well established that, during northern winter, El Niño-related sea surface temperature (SST) anomalies in the tropical Pacific produce a strong atmospheric wave response emanating from the tropics into both hemispheres. Furthermore, a number of recent experiments in which ensembles of atmospheric general circulation model (AGCM) simulations are forced with observed SSTs, indicate that the signal-to-noise ratios in the atmospheric circulation are substantially greater than one over much of the Pacific North American region, and that this is primarily due to ENSO. In contrast, during northern summer, the wave response to the El Niño Southern Oscillation (ENSO) SST anomalies is much weaker, and the nature of the link between the tropical SST and extratropical climate is unclear.

We have here performed a large ensemble of seasonal hindcasts using the NASA Seasonal-to-Interannual Prediction Project (NSIPP-1) AGCM forced with observed SST and sea ice. We focused on the northern summer cases. These cases consisted of 9-member ensembles for each year for the period 1980-1999. Each hindcast began with observed atmospheric initial conditions (from NCEP/NCAR reanalyses) in mid-May and extended to the end of August. The nine members of each ensemble differed only in the atmospheric initial conditions (separated by 12 hours and centered on 00z May 15). The soil conditions were those obtained from a previous long AMIP-style integration. All results presented here represent June-July-August (JJA) means.

Figure 36 shows the first two empirical orthogonal functions of the JJA mean observed SST over the 20 years (1980-1999). Together these functions explain about 40% of the variance in the JJA SST distributed approximately equally between the two modes. The first mode shows warming (cooling) in the eastern Pacific and the Indian Ocean. The second mode has warming (cooling) in the central tropical Pacific and cooling (warming) in the extratropical western Pacific and the tropical and North Atlantic. Figure 37 shows the correlation of the ensemble mean height (the signal) with each of the SST modes. The first mode is primarily associated with enhanced (reduced) heights throughout the tropics when the tropical SST anomalies are warm (cold). The correlations are largest over the eastern tropical Pacific and the Indian Ocean, where EOF 1 has the largest amplitude. The strongest correlations are confined to the latitude band +/-30°. The second mode indicates a strong zonally symmetric extratropical response, with enhanced heights in the tropical Pacific and reduced heights throughout the middle latitude bands of both hemispheres. There is also an indication of a wave component emanating from the central tropical Pacific.

A further analysis of the AGCM's 200mb height hindcasts shows that a substantial fraction of the predictable component of the height is associated with those two SST modes. We are currently examining the link between these modes and precipitation variability over the summer continents.

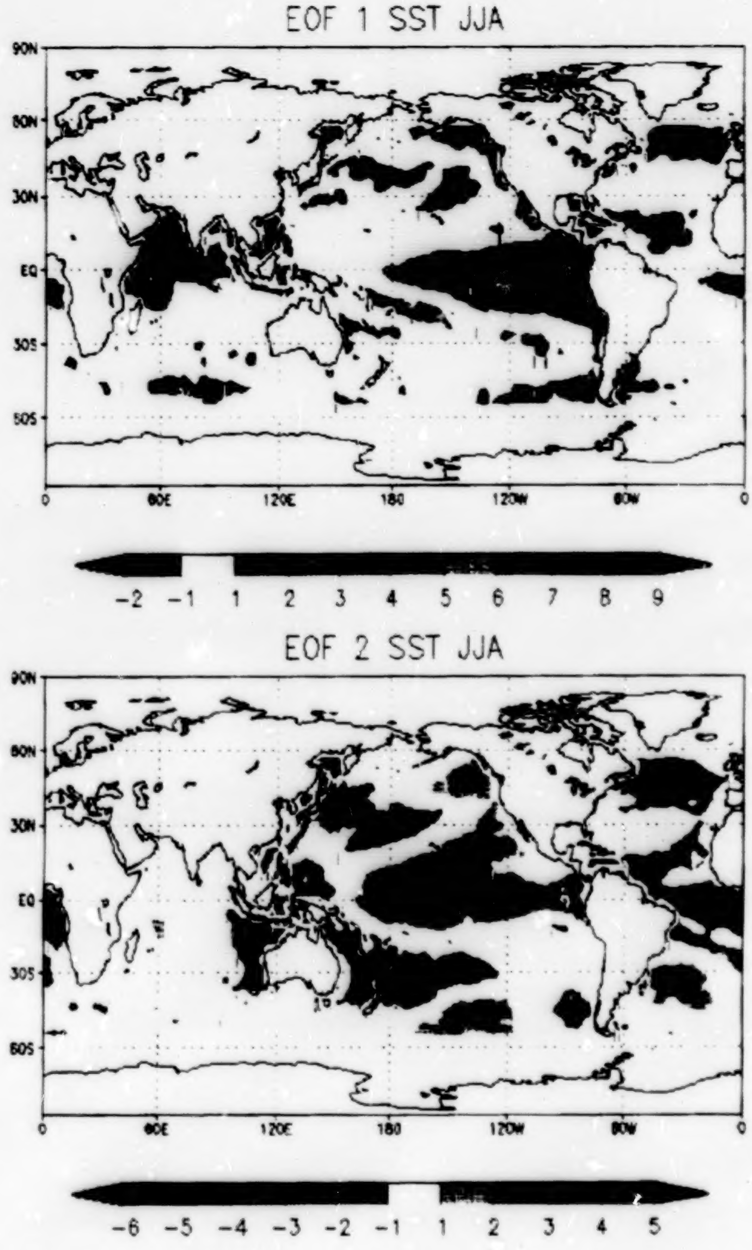


Figure 36. Top panel: First empirical orthogonal function (EOF) of sea surface temperature (SST) for June-July-August averages for 1980-1999. Bottom panel: Same as top panel except for the second EOF of SST.

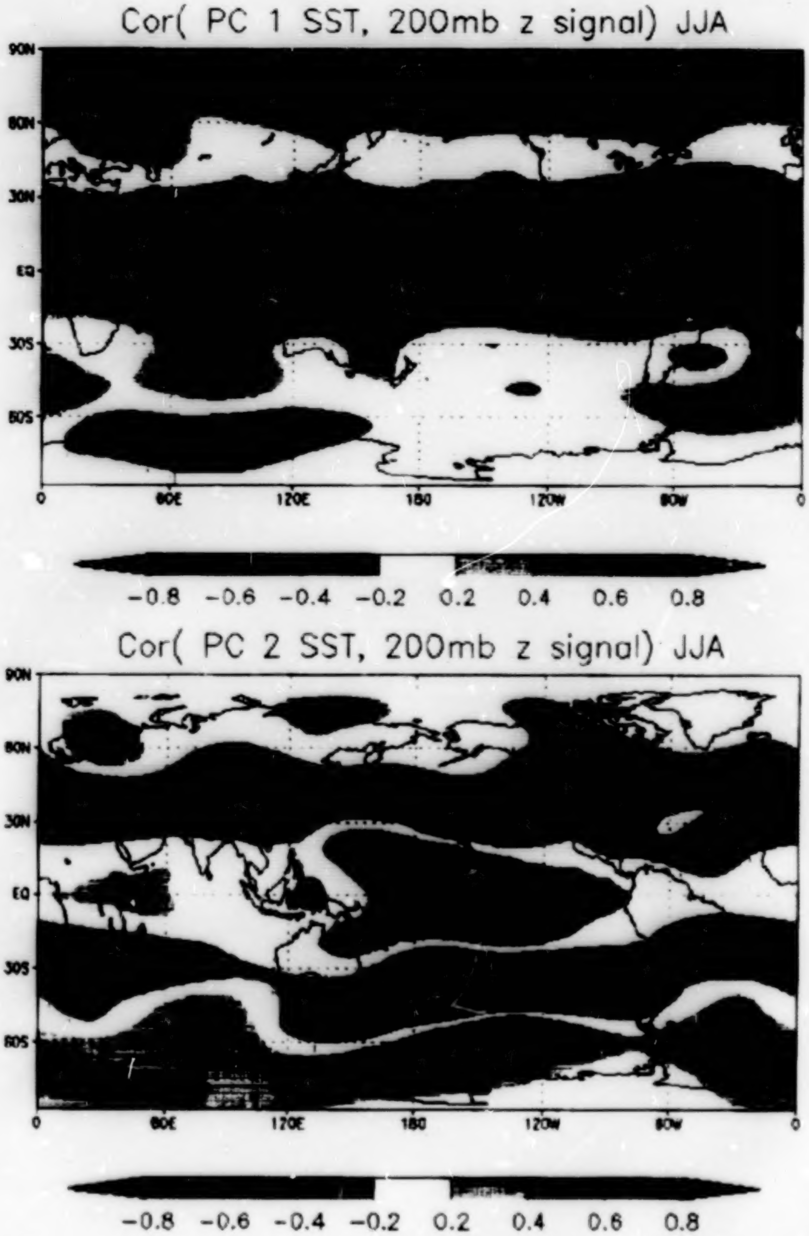


Figure 37. Top panel: Correlations between the first principal component (PC) of sea surface temperature (SST) and the AGCM ensemble mean 200mb height field at every grid point for June-July-August averages for 1980-1999. Bottom panel: Same as top panel except for the second PC of SST.

Siegfried Schubert, Code 910.3 (Siegfried.D.Schubert.1@gsfc.nasa.gov) and Max Suarez, Code 913

An Analysis of the Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is a well-known and important component of tropical variability on intraseasonal time scales. The MJO is clearly seen in the upper tropospheric velocity potential field as an eastward-traveling zonal wave number one structure varying on time scales of 40 - 60 days. The MJO also manifests itself in a number of other fields. Perhaps most importantly, it has a dominant signature in large-scale tropical heating and precipitation variability. It thus plays an important role in the hydrological cycle of the tropics and subtropics (in particular the Asian summer monsoon). A number of studies suggest that the MJO also has a significant impact on the extratropics (for example in the southwestern United States), and that the MJO may enhance forecasts on weekly to monthly scales. On seasonal and longer scales, the MJO is primarily a source of noise superimposed on the slower components of the climate system. We don't yet know whether the rectified signal of the MJO (the "envelope" of noise) is predictable on time scales longer than individual MJO events, and whether the noise is important for proper simulation of the slower modes (e.g., ENSO) in coupled models.

The immediate goal of this project is to perform a systematic analysis of the MJO from observations and currently available long-term reanalysis data. The longer term goals are (1) to develop diagnostic tools to routinely assess the veracity of the MJO in general circulation model simulations and assimilated data, (2) to develop a better understanding of the predictability of the MJO, and (3) to assess the role of the MJO in ENSO.

The left panel of Figure 38 shows the MJO in terms of the first complex empirical orthogonal function (CEOF) of the 200mb velocity potential field based on the NCEP/NCAR reanalysis for the period 1979-1998. All fields shown here are filtered to retain only time scales between 20 and 90 days. The CEOFs are ideal for representing traveling waves and in this case we capture 3/4 of the variability in the velocity potential field in a single mode. The figure shows the evolution of the wave one mode over a complete cycle. The left panel is the same as the right, except for NOAA outgoing longwave radiation. This field also shows eastward propagation, but the signal is largely confined to the eastern hemisphere.

Figure 39 shows the time evolution of the real part of the first EOF of the velocity potential field (green line) and the rectified signal (red line). During some periods the MJO activity clearly lasts considerably longer than a single oscillation of the MJO. An extreme case is 1979 during which the MJO was active almost the entire year, and it went through about 7 cycles. Still other years the MJO is for the most part weak and poorly define (e.g. 1989). These results serve as the basis for an ongoing study of the structure, forcing and predictability of the MJO in observations and models on a wide range of time scales.

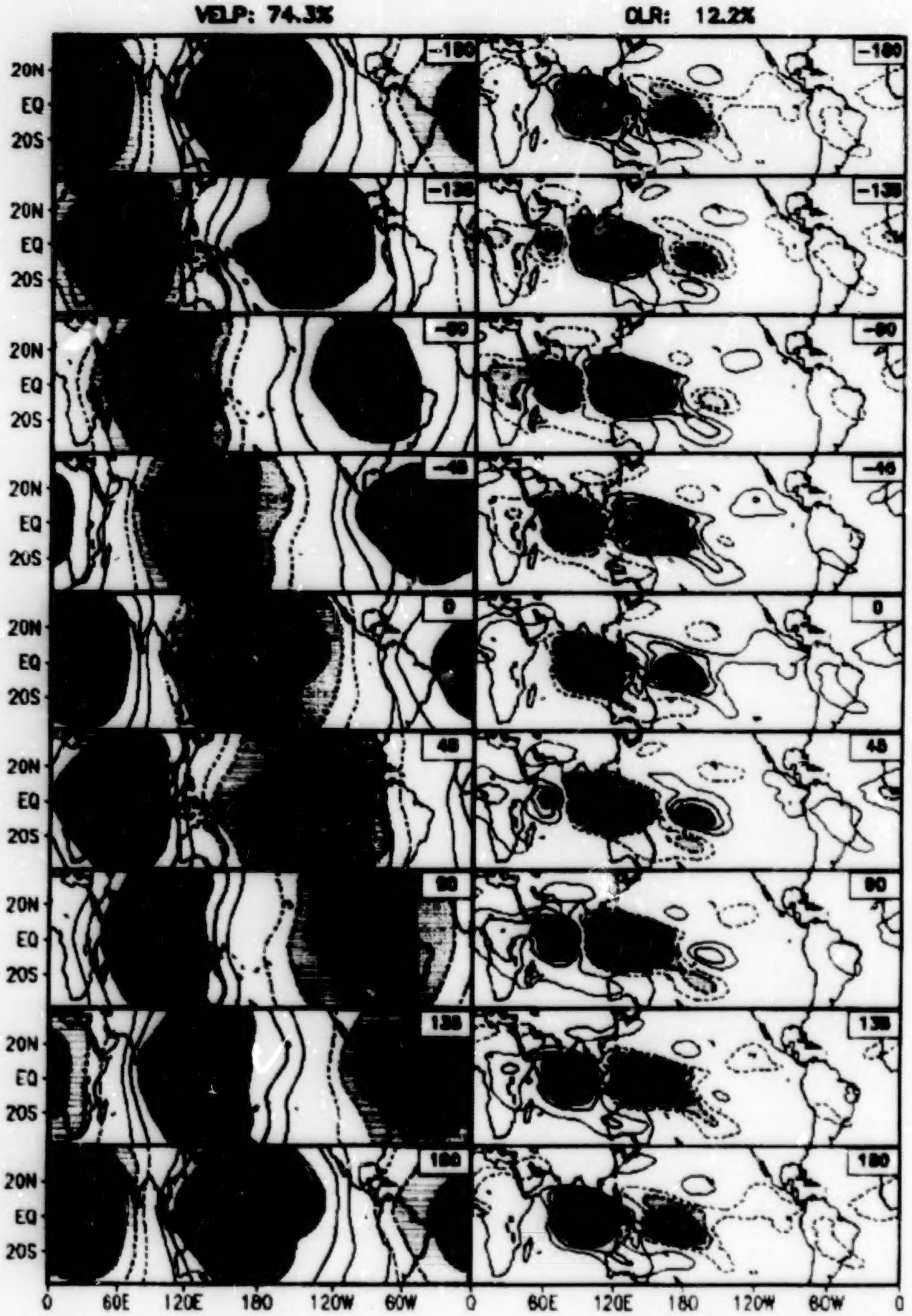


Figure 38. Left panel: One cycle of the first complex empirical orthogonal function (CEOF) of the 200mb velocity potential (20-90 day filter) based on NCEP/NCAR reanalysis data for 1979-1998. Right panel: Same as left panel except for NOAA OLR.

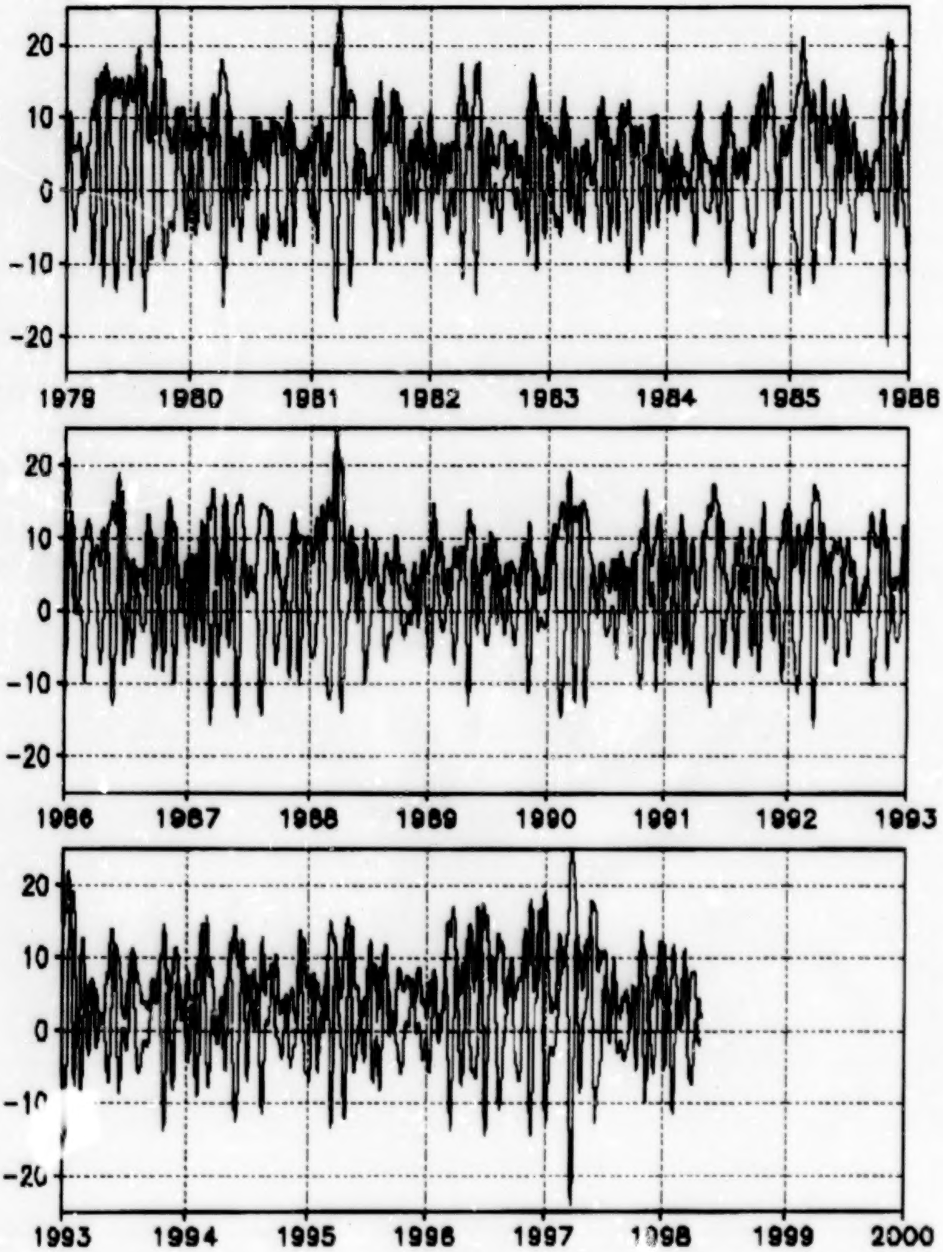


Figure 39. Time series of the modulus (red line) and real part (green line) of the first complex empirical orthogonal function (CEOF) of the 200mb velocity potential (20-90 day filter) based on NCEP/NCAR reanalysis data for 1979-1998

Siegfried Schubert and Yehui Chang, Code 910.3 (Siegfried.D.Schubert.1@gsfc.nasa.gov)

GEOS Ozone Data Assimilation System

The GEOS ozone data assimilation system became operational in January 2000. It has been running in near-real-time and providing global 3-dimensional ozone analysis fields in support of the instruments on the EOS Terra satellite. The ozone analysis fields are obtained by assimilation of the Total Ozone Mapping Spectrometer (TOMS) and the Solar Backscatter Ultra-Violet/2 (SBUV/2) instrument ozone observations into an ozone transport model.

The upper panel of Figure 40 shows an example of the total column ozone analysis produced by the system (i.e., integral of the ozone amount in a vertical column of the atmosphere, measured in Dobson units). The TOMS observations of total column ozone for the same day are shown in the lower panel of the figure with unobserved regions shaded in white. Although TOMS takes 24 hours to obtain the near-global coverage shown here, the analysis produced by the system is global and instantaneous. The analysis fills temporal and spatial gaps in TOMS observations: between the orbits in the tropics and in the unobserved polar night region in the northern high latitudes. The analyzed ozone agrees well with the input TOMS and SBUV observations. In addition, the transport model captures the dynamical variability in the ozone field. Comparisons with independent measurements have shown very good agreement of the ozone analysis profiles with independent profile measurements from the Halogen Occultation Experiment on board NASA's Upper Atmosphere Research Satellite.

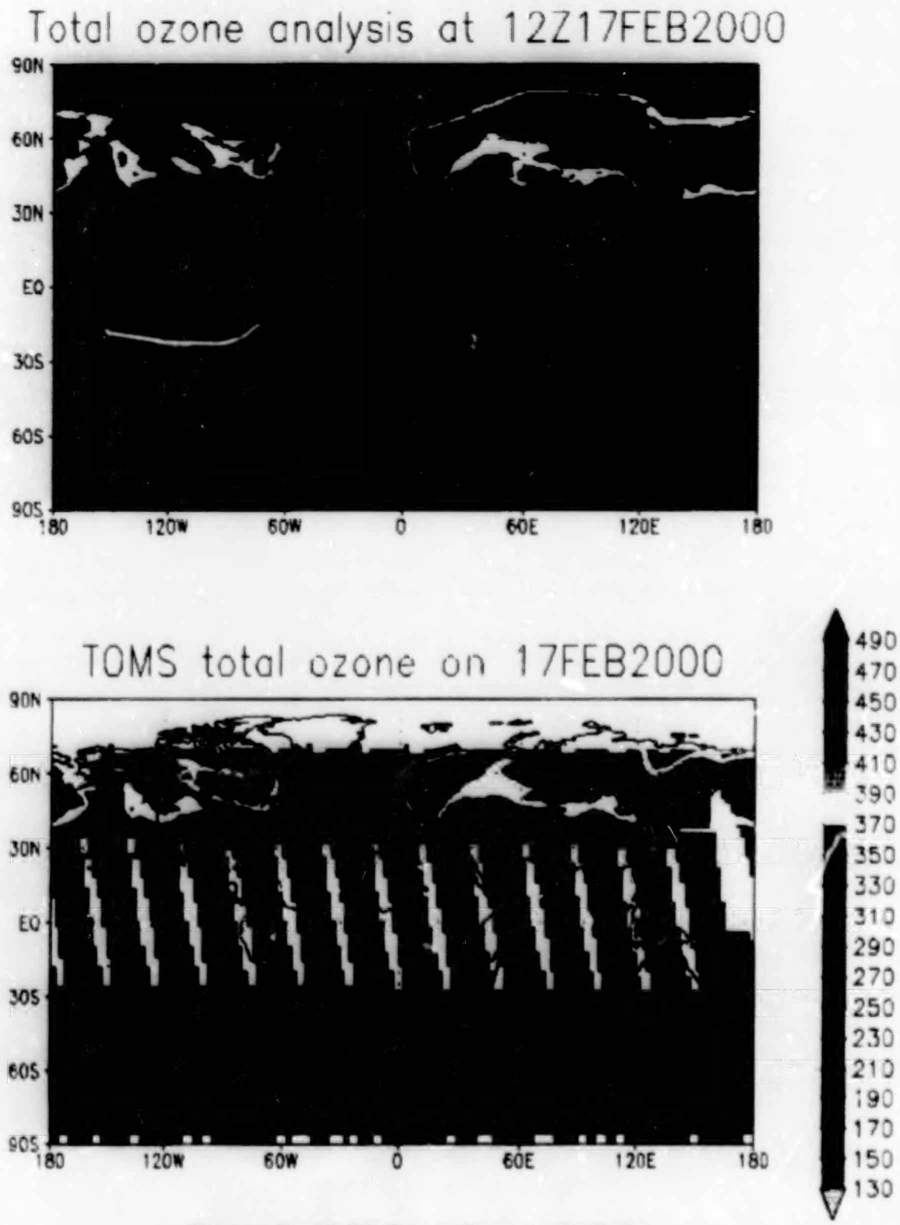


Figure 40. GEOS Ozone Data Assimilation.

Lars Peter Riishojgaard, Code 910.3 (larspr@dao.gsfc.nasa.gov)

Land Temperature Assimilation

The accurate representation of the land surface in weather and climate prediction models is critical, due to its partitioning and complex dynamic storage of water, energy, and carbon. Land surface temperature is a critical value for NASA instrument teams and Earth scientists, and it is one of the few land surface state variables readily observable from space. While land surface models have progressed significantly over the last two decades, error and bias of the land temperature can occur because of interactions with the atmospheric climate and meteorology (through clouds, radiation and precipitation) in addition to uncertainties in the land processes (specification and heterogeneity).

To better represent the land surface boundary in the DAO reanalysis system, we have developed a method to assimilate skin temperature into land models. Our development and testing has progressed through scientific collaboration between the Global Land Data Assimilation System (GLDAS) research group in the Hydrological Sciences Branch (Code 974) and the Data Assimilation Office (Code 910.3). A key finding of this work was that overcoming diurnal biases requires more than a traditional long-term bias correction. By extending the bias correction to compensate for long-term diurnal biases, we significantly improved the representation of the surface temperature. An effort is underway to integrate the skin temperature assimilation into the DAO reanalyses.

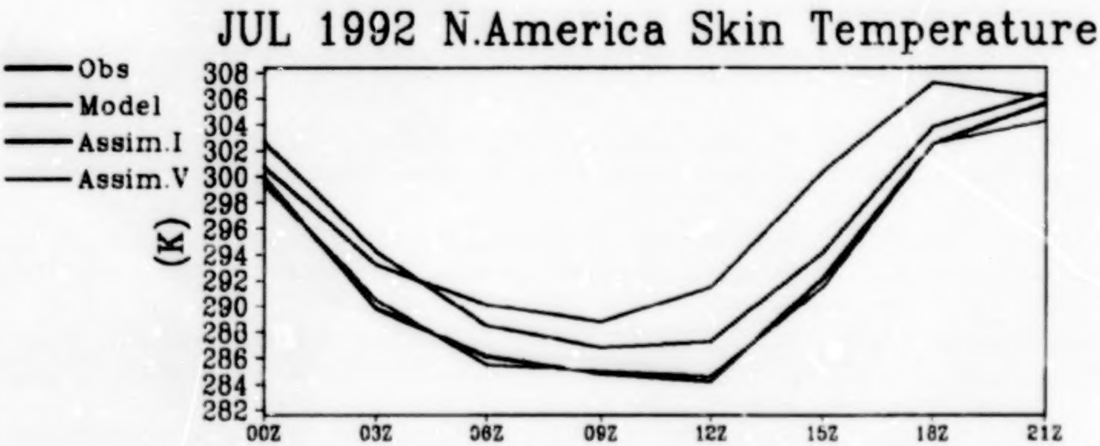


Figure 41. Monthly mean diurnal cycle area-averaged for the land points of central North America. ISLSCP Observations (Black), Model simulation (Red), Assimilation Experiment I (Blue) and Assimilation Experiment V (with incremental semi-diurnal bias correction) (Green). Note that in this case we are assimilating ISLSCP skin temperatures.

Arlindo da Silva, Code 910.3 (Arlindo.M.Dasilva.1@gsfc.nasa.gov) or Paul Houser, Code 974 (Paul.R.Houser.1@gsfc.nasa.gov)

Hurricanes

Numerical Modeling of Hurricanes

We employed a mesoscale numerical weather prediction model to simulate hurricanes, using high horizontal-grid resolution (1-4 km). Specifically, we simulated Hurricane Bob (1991) at a 4-km grid resolution to investigate the role of surface fluxes and vertical mixing in the boundary layer on storm intensity and structure.

We used four different boundary layer scenarios. Each scenario varied in its formulation of vertical mixing within the boundary and the surface fluxes. Our simulations revealed strong sensitivity of the precipitation structure and storm intensity, as measured by the surface pressure within the eye and by maximum wind speed within the eyewall. To isolate the separate effects of vertical mixing and surface fluxes, we performed some simulations using multiple surface flux schemes with a single vertical mixing scheme and others using multiple vertical mixing schemes with a single surface flux scheme. These experiments indicated that simulated intensity is determined largely by the surface fluxes rather than by the vertical mixing. There was one exception. In that simulation, excessively deep vertical mixing acted to dry the lower boundary layer and reduce hurricane intensity.

A 1.3-km grid scale simulation of the same storm provided unprecedented detail of the kinematic, thermodynamic, and cloud microphysical structures within the storm. Our analysis of heat and momentum budgets for this storm suggests an important role of horizontal eddy heat and momentum transports into the eye. These transports act to intensify the warm core and increase winds inside the eyewall. Our findings agree with theoretical predictions using vortex Rossby wave concepts and vortex instability analyses. In collaboration with researchers at Colorado State University, we are analyzing this simulation to study the evolution of vortex Rossby waves and their relationship to storm intensification and precipitation structure.

Hurricane modeling is often difficult because large-scale analyses seldom include an adequate representation of the hurricane vortex. Often, we must insert a "bogus" vortex to represent the initial hurricane structure. This bogus vortex is generally an oversimplification of the existing storm and can result in forecast errors associated with adjusting the model to initial imbalances. We have devised a method for creating a bogus vortex that uses 4-dimensional variational data assimilation to minimize initial imbalances.

We applied this method to hurricanes observed during the NASA Convection and Moisture Experiment (CAMEX-3) in 1998. The methodology involves assimilation, over a short time period, of bogus surface pressure and wind distributions that reflect observed conditions and the horizontal scale of the vortex. During the assimilation period, the velocity and mass fields are adjusted so that they coincide with the specified surface pressure and wind distributions and the dynamical equations of the model. We applied this technique to Hurricane Georges, which occurred during CAMEX-3, prior to its landfall in Puerto Rico. In our simulation, we used a 36-km grid for the assimilation of the bogus vortex and a 12-km grid for the forecast. Our results (Figure 42) show a dramatic improvement of the intensity and rainfall forecast compared to a simulation without the bogus vortex.

We also successfully applied the bogus vortex technique to the case of Hurricane Bonnie (1998). In this case, the forecast was conducted using a 4-km grid scale to better resolve the cloud microphysical processes and details of the storm structure. Validation of the model against observations is essential for identifying shortcomings of the model physics that contribute to forecast errors and making improvements to the model. We are validating our simulated precipitation structure against TRMM precipitation radar reflectivity data and CAMEX-3 aircraft data. Our comparison to TRMM (Figure 43) suggests that the model is successful in capturing the observed asymmetry of the precipitation field. However, the model tends to produce reflectivities that are too large and a distribution of rain that is more convective and less stratiform than that observed by TRMM. The differences between simulated and observed rainfall help us improve the model cloud microphysics.

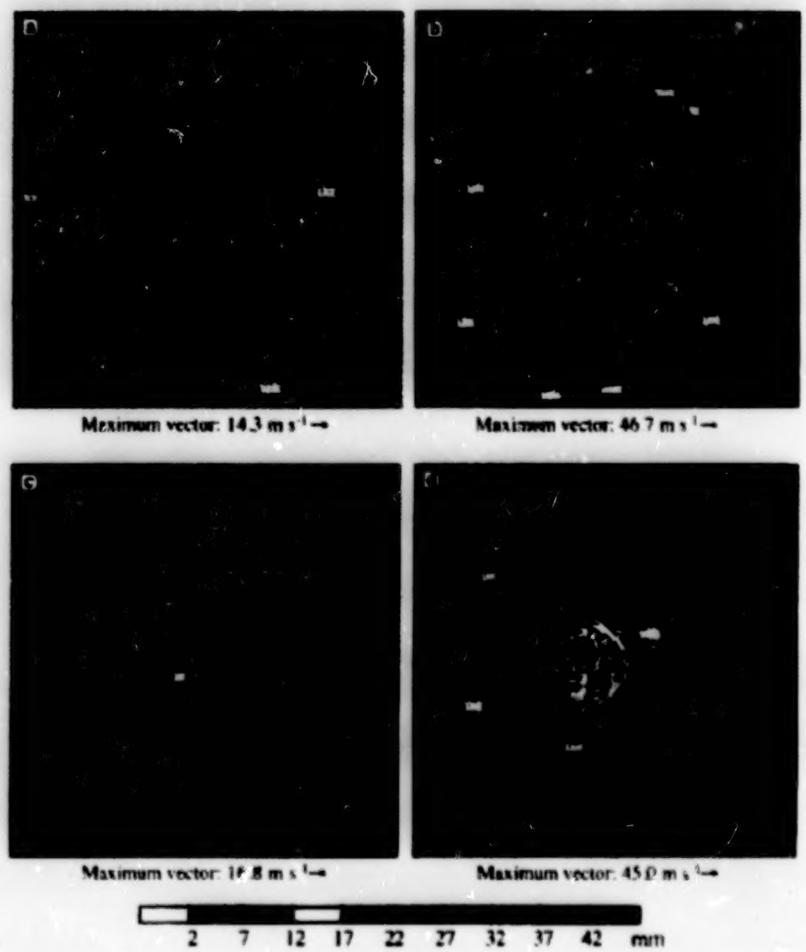


Figure 42. Panels demonstrate the impact of assimilation of a bogus hurricane vortex into the model initial conditions for a simulation of Hurricane Georges (September 1998). Upper panels show initial sea-level pressure (contours at 4 mb intervals) and 850 mb wind vectors for simulations (a) without a bogus vortex and (b) with a bogus vortex. Hurricane Georges at this time was a major hurricane just east of Puerto Rico. The storm is poorly defined in the large-scale analysis used to generate the model initial conditions in (a). Inclusion of the bogus vortex substantially improves the initial storm structure in the model. Lower panels show the 6 hour forecasts of sea level pressure, 850 mb winds, and 6 hour accumulated precipitation for the simulations (c) without and (d) with the bogus vortex. Substantial improvement of the precipitation forecast is obtained with the bogus vortex.

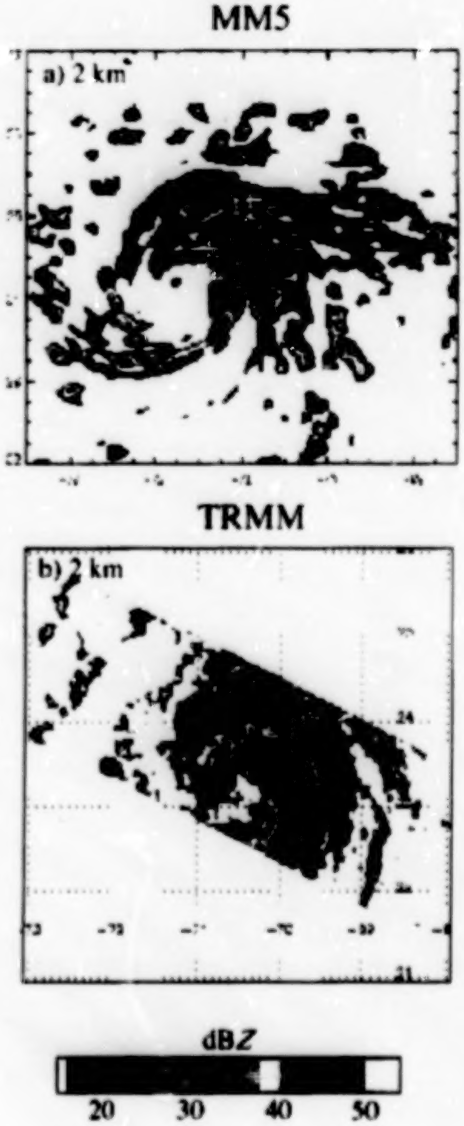


Figure 43. Comparison of MM5 simulated radar reflectivity (a) and TRMM precipitation radar reflectivity (b) at 2 km above mean sea level. For both panels, the display area is 5° latitude by 5° longitude and the color table is identical. The model captures the asymmetry of the rainfall pattern, with most of the rainfall to the north and east of the center.

Scott Braun, Code 912 (Scott.A.Braun.1@gsfc.nasa.gov)

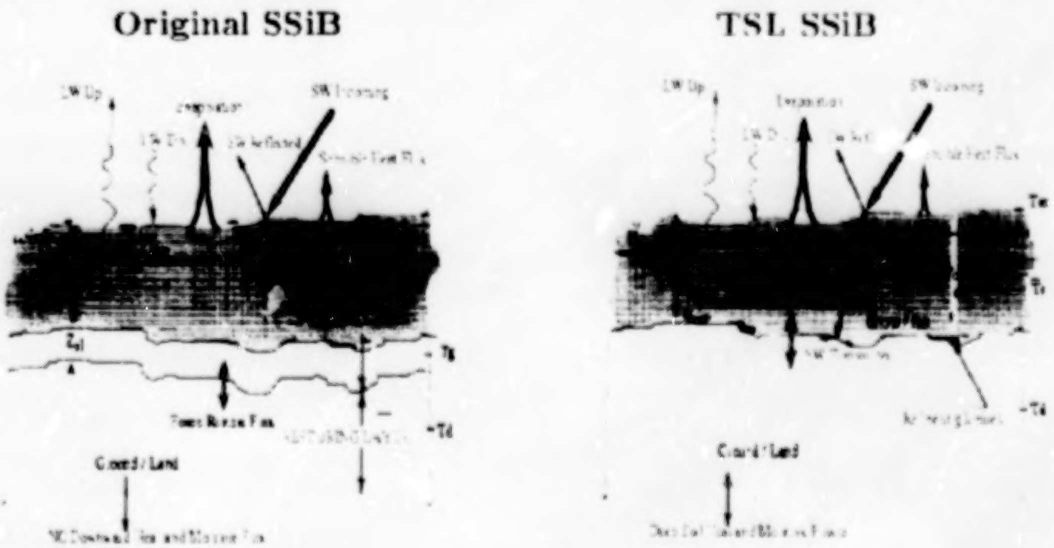
Physical Processes

Force-Restore Snow Physics in SSiB

Laboratory staff designed a model to remedy systematic weaknesses in the snow processes of Simple SiB (SSiB). The new model separates the snow-pack from land so as to allow the snow-pack to have its own temperature and energy-exchange processes (Figure 44, left diagram). This snow physics led to better snow-melt and melt-water recharge timings.

We introduced a force-restore snow-layer atop the rest of the snow pack (Figure 44, right diagram) to further reduce the remaining time delay in the simulated snowmelt (as derived from systematic investigations of snowmelt and melt-water discharge for the Russian Wheat Belt region using GSWP ISLSCP Initiative I data sets). The force-restore snow-layer now produces better diurnal amplitude of snow-surface temperatures while attenuating the surface solar-flux more realistically. It also generates some mid-winter snowmelt during the warm spells, enabling the snow accumulation to agree better with observations. Thus, the revised snow-model not only improves the remaining delay in the snowmelt (varying from 1-4 weeks), but is also accompanied by several overall improvements of the hydrologic processes that are central to land-atmosphere interactions.

In previous work, we described (a) inaccuracies in the satellite retrievals of snow under dense forest canopies, (b) assumptions in modeling, and (c) possible cold bias of the ISLSCP surface air temperature data. Nevertheless, we now show significant improvements in the snow-accumulation/snow-melt simulation in response to improved snow-physics.



Original SSiB

- **One combined layer for snow plus diurnal ground layer with $C_m = C_g; T_m = T_g$**
- **Shortwave is reflected or absorbed by combined layer**
- **Combined layer and annual layer beneath exchange fluxes using force-restore algorithm**

References:

Xue et al., J. Climate, 1991; Sellers et al., JAS, 1986
Mocko and Sud, Earth Interactions, 1998

TSL SSiB

- **Snow layer is separated from ground, with own prognostic temperature and heat capacity; snowpack is divided into a diurnal layer atop a bulk layer**
- **Shortwave is partially absorbed by the snow or transmitted to ground**
- **Heat transferred radiatively through thin air gap between ground and snow**
- **Snowmelt can re-freeze and warm the ground**
- **One ground layer acts as an annual force-restore layer atop an infinite layer with fixed temperature**

References:

Sud and Mocko, AMS, GEWEX/GCIP, 1999

Figure 44. New snow-physics model development.

Yogesh Sud and David Mocko, Code 913 (Yogesh.C.Sud.1@gsfc.nasa.gov)

Cirrus Cloud Models

Laboratory staff completed a primary analysis of results from the GCSS WG2 Idealized Cirrus Model Comparison Project. The 17 models participating in this project represent the state of the art. They range in complexity from very high resolution 3-dimensional (3-D) large eddy simulation (LES) models, to 3-D and 2-D cloud resolving models (CRMs), to single column model (SCM) GCMs. The microphysical, and radiative, components are similarly varied, ranging from simple relative humidity (bulk) schemes to fully size-resolved (bin) treatments of microphysical growth and development.

A key finding is that significant scatter exists in the results from the various state-of-the-art models for each of the idealized cases that were simulated. These cases included "warm" and "cold" cirrus forming in a neutrally stratified, versus stably stratified, supersaturated layer (RHI = 120%) under nighttime conditions (infrared radiative processes only versus no radiation) subject to relatively weak forcing (imposed cooling equivalent to adiabatic ascent at 3 cm s^{-1}). In the "warm" cirrus case, differences of up to a factor of 2 were found in horizontally averaged, vertically integrated ice water path (IWP). These differences appear even among the "built-for-cirrus" cloud-resolving models (CRMs) after 4 hours of development/forcing. This is the least detailed measure of model result. Differences grew appreciably in the subsequent decay phase when the forcing was turned off. Moreover, even greater differences arose in the "cold" cirrus case. Results from "heritage" CRMs were somewhat more divergent. ("Heritage" CRMs were models originally built to simulate deep convection or boundary layer clouds.) Results from the SCMs spanned the range of CRM results. These results characterize the current state of knowledge on cirrus cloud processes, indicating that significant uncertainties exist with resultant implications for large-scale climate models where cirrus cloud radiative effects play an important role.

A second major finding is that the results of the bulk "built-for-cirrus" models diverge systematically and substantially from those of the bin models. This is especially true for cold cirrus and even for gross parameters such as horizontally averaged, vertically integrated ice water path (IWP). Smaller, more numerous ice crystals in the bin model simulations of cold cirrus would account for the substantially greater ice water path and internal circulation intensity, and the smaller effective ice water fall speeds. (Ice water fall speed was an independent parameter in some bulk models but required bin-by-bin calculation in bin models.) The same explanation holds for significant differences in gross cloud geometry (upward growth of cloud top versus relatively static cloud top in bulk model simulations, Starr et al., 2000). These results strongly focus the science issues needing observational confirmation. The results also provide new insights into how this confirmation might be accomplished, even with the present observational limitations and uncertainties.

This work was a key topic of an international workshop (Joint GCSS Working Group on Cirrus Cloud Systems with the GCSS Working Group on Extratropical Layer Cloud Systems) and was presented to special GEWEX session of Spring 2000 AGU meeting and as lead paper at the 13th International Conference on Clouds and Precipitation in August 2000.

David Starr, Code 912 (David.O.Starr.1@gsfc.nasa.gov)

7. EDUCATION AND PUBLIC OUTREACH

The Laboratory for Atmospheres actively participates in NASA's efforts to serve the education community at all levels and to provide information to the general public. The Laboratory's educational outreach component is consistent with the Agency's objectives to enhance educator knowledge and preparation, supplement curricula, forge new education partnerships, and support all levels of students. Laboratory activities include continuing and establishing collaborative ventures and cooperative agreements; providing resources for lectures, classes, and seminars at educational institutions; and mentoring or academically-advising all levels of students. Through our public outreach component, we seek to make our scientific and technological advances broadly accessible to all members of the public and to increase their understanding of why and how such advances affect their lives.

Interaction with Howard University and Other Historically Black Colleges and Universities

A part of NASA's mission is to initiate broad-based aerospace research capability by establishing research centers at the nation's Historically Black Colleges and Universities (HBCUs). The Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) was established in 1992 at Howard University (HU) in Washington, D.C., as a part of this initiative. The Laboratory for Atmospheres started its collaboration with CSTEA in the second 5-year period of NASA funding. It is the goal of NASA and mission of CSTEA to establish at Howard a self-supporting, world-class facility for the study of terrestrial and extraterrestrial atmospheres, with special emphasis in training African Americans in aerospace sciences and engineering.

The Laboratory continues its research and educational activity with Howard University's CSTEA program. A Technical Review Committee site visit has been held yearly to evaluate the CSTEA program, to make recommendations for the program's research and collaborative interactions with the Laboratory, to help the program with its strategic planning for future growth, and to help the program develop new funding sources. The Laboratory works closely with CSTEA faculty to promote the Howard University Program in Atmospheric Sciences (HUPAS). HUPAS is the first MS- and PhD- granting program in atmospheric sciences at an HBCU and the first interdisciplinary academic program at Howard University. Scientists from our Laboratory contribute to the HUPAS program as lecturers, advisors to students, and adjunct professors teaching some of the courses.

The Laboratory continues its enthusiastic support for the Goddard Howard University Fellowship in Atmospheric Sciences (GoHFAS) program. GoHFAS was established in 1999 to broaden and strengthen the research and educational opportunities of underrepresented minorities. The students attend a summer program at Howard University where they engage in research with mentors at HU, GSFC or NOAA. They attend a for-credit class in atmospheric science and a technical writing and presentation class. They receive fellowships at their home institutions during their senior year and are given an opportunity to come to HU during the winter break to continue their research. Six of the eight students from the first year of the program are now attending graduate school. Five of them are in the HUPAS program at HU. Four of the eight students from the second year have applied to Howard University.

The Laboratory hosted two faculty members on sabbatical from Howard University. A recent HU graduate is a new member of the Laboratory's Atmospheric Chemistry and Dynamic Branch and is pursuing his doctoral degree in the chemistry department while contributing to the research of the Laboratory.

Graduate Student Summer Program

The Laboratory for Atmospheres participated in a program administered by the Universities Space Research Association, in collaboration with the Goddard Space Flight Center's Earth Sciences Directorate. This program offers a limited number of graduate student research opportunities each summer. The program is designed to stimulate interest in interdisciplinary Earth science studies by enabling selected students to pursue specially tailored research projects in conjunction with Goddard scientific mentors. This program is now administered by the GEST Center. For further information, consult the World Wide Web (http://www.umbc.edu/gest/) under Student Opportunities.

University Education

At the university level, Laboratory scientists have taught undergraduate and graduate courses at universities, given seminars and lectures, participated in mentoring teachers and students under a variety of GSFC programs, and advised degree-seeking students. Four Laboratory scientists supervised undergraduate students and twenty-one supervised graduate students. Twenty-two Laboratory scientists have official affiliations (i.e. adjunct or visiting professor) with a university and fourteen regularly teach university-level courses.

Our scientists are involved as teachers in a variety of other settings. In a venture with other Goddard Laboratories, our scientists participated in delivering an MIT course for credit on the subject of Techniques in Remote Sensing. This course for MIT students took place during the winter semester break 1999-2000. The course was an Independent Activity Period course (IAP) during which students spent a week at Goddard and a week at MIT. The Laboratory presented lectures for 1 1/2 days during this seminar series. Each year our Laboratory hosts a visit of the AMS Fellowship winners, who are treated to informal lectures to acquaint them with the breadth of our research.

Laboratory scientists mentored five undergraduate students and nine graduate students during the summer of 2000 through various programs. Additionally, the Code 910/970 Summer Institute on Atmospheric and Hydrospheric Science brought about 15 undergraduate students to Goddard for two months of intensive research. Some of the students return to the Laboratory to work on other programs, and some are mentored by Laboratory scientists for their thesis work at their home institutions.

K–12 Education

Laboratory staff participated in K–12 education in a variety of ways. Laboratory scientists routinely presented lectures and demonstrations to K–12 schools and youth groups to help develop an early interest in science. Many Laboratory scientists have also mentored students in grades K–12. The Eleanor Roosevelt High School Science and Technology Internship Program enabled high school students to perform research on mesoscale atmospheric processes under the mentorship of Laboratory scientists. This program exemplifies a unique three-way partnership between the Laboratory, its contractors, and Eleanor Roosevelt High School. Members of the Laboratory served as judges for local science fairs and made presentations at High School Career Days to foster interest in NASA-related research. Additionally, Laboratory scientists continue to

mentor K–12 students. One Laboratory scientist was awarded Director's Discretionary Funding (DDF) for FY2000 for outreach related to Girl Scouts of Maryland and Earth science education. Another scientist volunteered and served as a judge for Goddard's "Virtual Science Fair," in which high school students submit reports on their research projects to Goddard by e-mail. Goddard scientists then e-mail advice back to them and, ultimately, judge the merit of their final work. One scientist worked with 7th grade students at St. Hugh's on "Seek Out Science," a project sponsored by ABC-TV Channel 7. This educational outreach teaches students how many of us chose our scientific careers and what steps we took to achieve our positions. Students also learn about data assimilation as a science and as a NASA endeavor.

In the areas of curriculum development and educator training, the Laboratory played a significant role in 2000. Several Laboratory scientists served on panels for local school districts in Prince George's County and Montgomery County to assist in developing new curricula. As a result, Earth science material has been or will be included as part of an enhanced science program at several area schools.

Public Outreach

Informing the public of how their tax dollar investments are working for them within the Laboratory is a critical subset of the Center and Agency public outreach mission. Laboratory scientists, working with other Laboratories at Goddard and outside institutions, have passed their knowledge and interest in Earth and space science to the general public via public information and education programs.

TRMM continues its comprehensive Education/Outreach program, in which Laboratory personnel are funded by the DDF to promote TRMM science to the public. This project develops outreach strategies for TRMM science and technology. These strategies include the development of broadcast visuals and educational curriculum focusing on the Tropical Rainfall Measuring Mission. These packages are available on the TRMM Web site (http://trmm.gsfc.nasa.gov/) and have been reviewed as a part of the ESE Education product review. They are currently under revision. TRMM scientists regularly appear on major media outlets (Earth and Sky Radio, CBS, NBC, ABC, and CNN) in support of the mission. In addition, Laboratory personnel have spoken at and conducted several outreach workshops in support of TRMM. The TRMM DDF principal investigator met with representatives of the African Technology Development Program and Howard University to discuss how TRMM science and resources could be useful in African countries. Further correspondence is anticipated.

The TRMM DDF Education and Outreach study has led to a feature story entitled *Seeing into the Heart of a Hurricane*. The story is available in the features section of the Earth Observatory Web site, http://earthobservatory.nasa.gov/, and features information and data from TRMM.

In addition to TRMM, Laboratory science stories routinely achieved major media exposure. The Goddard Public Affairs Office estimates that 50 million viewers tuned in to Laboratory-related science news in 2000. The Laboratory's scientists, images, and animations have appeared in the media, including TV segments with ABC's Peter Jennings and NBC's Tom Brokaw, and top billing of Goddard and NOAA images of hurricanes in *Time*, *Life*, and the covers of *Popular Science*, *Newsweek*, *Der Spiegel*, *National Geographic*, and *The Weekly Reader*. Four Laboratory scientists were featured in popular radio programs for public education, reaching a combined audience of more than 2 million listeners. They discussed subject matter related to ozone, global warming, and clouds. Also, Laboratory members frequently write invited popular articles; e.g., for the *Encyclopedia for Atmospheric Sciences*.

The Laboratory's presence in the media will likely expand due to new initiatives established in 1999 and continued into 2001. Collaboration with the Discovery Channel was initiated with Total Ozone Mapping Spectrometer Camera (TOMS-CAM) to raise awareness about atmospheric ozone issues. Various projects are in development to release TRMM, TOMS, and AVHRR products to the public through The Weather Channel. Two groups within the Laboratory were awarded DDF resources to produce a documentary on ozone and to develop a presentation for popular weather broadcasters. A Laboratory scientist has an Education DDF proposal in collaboration with Cindy Howell of Goddard PAO to fund a team of scientific journalists to put together a prospective story for a possible ozone documentary that could be sold to one of the educational TV shows like NOVA.

Laboratory efforts were not limited to formal outreach outlets (e.g. media). Several informal public outreach venues were utilized. Laboratory staff created a permanent display on the 3-dimensional temperature structure of the Earth for the GSFC Visitor Center. The TRMM Office provided a booth for visiting teachers. Laboratory scientists furnished input to the Mad Scientist Network, a group based at Washington University in St. Louis that answers questions submitted to them by students all over the world. Our scientists also contributed to Goddard Scientific Visualization Studio efforts to collaborate with the Smithsonian Institution, the American Museum of Natural History, Disney World EPCOT, and the White House in communicating scientific discoveries to the public.

GOES Web Server

This Web server continues to provide GOES images on-line, including full-resolution images of all sectors of the United States for the most recent two days. In addition, there are extensive scrapbooks of digital movies and pictures of important weather events observed by the GOES-8 and GOES-9 satellites since they were launched in 1994 and 1995, respectively. The Remote Sensed Data (RSD) server (http:rsd.gsfc.nasa.gov) has been judged by NASA-HQ to be one of the 20 most popular NASA Web sites during the year 2000. The science administrator of RSD supplies GOES-derived high-quality graphics and severe storm animations to the Visualization Analysis Laboratory (VAL), to GSFC Public Affairs Office (PAO), and directly to the public via the Internet. During active hurricanes, the GOES section of the RSD Web server is accessible to the general public.

EOS Terra Outreach Synopsis

Under the direction of Yoram Kaufman (Code 913), Claire Parkinson (Code 971), and David Herring (Code 913), a coordinated effort is underway to foster greater cooperation and synergy among various outreach groups within the EOS community. As such, each of the activities described below receives contributions from various persons strategically located in different organizations and/or codes within the community.

The Terra Project Science Office has produced thousands of copies of a Terra mission overview brochure. The layout and design of the brochure, as well as funding for its printing, came from Code 900. Additionally, this brochure, as well as many more images, animations, and information, is available on the Terra Web site (http://terra.nasa.gov/), which is also maintained by the Terra Project. The Aqua project scientist and outreach scientist are also developing an EOS Aqua overview brochure.

The Terra and Aqua project teams created NASA's Earth Observatory Web site (http://earthobservatory.nasa.gov/). This Web environment is the NASA Web portal where the general public goes to learn about the Earth. It showcases new images and science results from

EOS missions. The focus in its first year of operation was Sea-viewing Wide Field-of-View Sensor (SeaWiFS), TRMM, Landsat-7, SeaWinds, and Terra. All resources produced for the Earth Observatory are freely available for use by the EOS community, museums, educators, public media, regional "stakeholders," environmental awareness groups, and interested members of the general public. While leadership for this site resides in Code 913, significant contributions to its development come from Codes 900, 902, 912, 921, 922, 923, 935, 971, and 3200 at the Jet Propulsion Laboratory, as well as the American Museum of Natural History and East Carolina University.

To provide overarching guidance and review for the Terra outreach activities, as well as to flag mature new science results ready for public release, an Executive Committee for Science Outreach (ECSO) continues to operate. This committee is chaired by Dr. V. Ramanathan, of the Scripps Institute's Center for Clouds, Chemistry, and Climatology. The purpose of this committee is to "harvest" new Terra science results that are ready for public release, as well as to help temper the presentation of new results with respect to socio-political implications they may have.

Finally, the Terra Project formed a Rapid Response Network to meet the public media's requirements for quick access to satellite imagery relevant to, newsworthy Earth events (e.g., severe storms, floods, El Niño, volcanic eruptions, wildfires, etc.). The Network is headed by David Herring (Code 913), assistant Terra project scientist. After launch, this network will enable us to access and produce remote-sensing imagery over targets of interest within hours to days after acquisition.

The Terra outreach group, under David Herring, worked with Ron Erwin (GSFC Code 100 Education Office) to launch the Terra Engineering Competition, which was open to high school students throughout Maryland. The competition was sponsored and promoted jointly by the Baltimore Museum of Industry, Towson State University, and NASA GSFC. The competition involves high school students grappling with and proposing solutions to a real-world problem that Terra engineers are working on. The competition began in mid-December 2000. We hope to stimulate other NASA centers and affiliated agencies to replicate the competition for their respective states, to get broader exposure for the mission.

Three major outreach Web sites are (1) the Terra homepage (http://terra.nasa.gov/), (2) the Earth Observatory (http://earthobservatory.nasa.gov/), and (3) the Visible Earth (http://visibleearth.nasa.gov/). The Terra homepage was published in February 1999, and since December of that year (when the mission launched), the site has received 1.8 million page views. The Earth Observatory first published on April 29, 1999, has received more than 6 million page views, averaging currently about 35,000 per day. The Visible Earth published on August 17, 2000, has already received about 2.7 million page views. The purpose of the Visible Earth site is to provide access to THE SUPERSET of all Earth science images, animations, and data visualizations produced by NASA for public release.

EOS Aura Education and Public Outreach Synopsis

The Laboratory for Atmospheres has responsibility for conducting the Education and Public Outreach program for the EOS Aura mission. Aura's Education and Public Outreach program has four objectives. The first objective is to educate students about the role of atmospheric chemistry in geophysics and the biosphere. The second objective is to enlighten the public about atmospheric chemistry and its relevance to the environment and their lives. The third objective is to inform geophysics investigators of Aura science, and thus enable interdisciplinary research. The final objective is to inform industry and environmental agencies of the ways Aura data will

benefit the economy and contribute to answering critical policy questions regarding ozone depletion, climate change, and air quality.

To accomplish these objectives, the Laboratory has partnered with several institutions which have established infrastructures that reach large audiences in the areas of formal and informal education. The GLOBE program and the American Chemical Society (ACS) will carry out formal EOS Aura education outreach effort.

GLOBE is a worldwide network of students, teachers, and scientists working together to study and understand the global environment. Students and teachers from over 9,500 schools in more than 90 countries are working with the science community to learn more about the environment by making observations at or near their schools and reporting their data through the Internet. A protocol is being developed for students to measure UVB and overhead aerosols in collaboration with Aura research. The protocol will help students understand the implications of ozone and aerosol changes and their relationship to incident UVB. These data could also be valuable for validating Aura data, which takes comparable measurements from orbit. Since the Aura mission involves Partners from Europe, their Education and Public Outreach programs will also support the GLOBE international components.

The American Chemical Society (ACS) distributes its teaching magazine, *ChemMatters*, to 20,000 high school teachers. Over the next three years, the ACS will produce four issues of *ChemMatters* highlighting topics related to atmospheric chemistry, including space-flight technology, remote-sensing methods, ozone and climate observations, and forthcoming results from Aura measurements.

Our outreach to the general public will also include an exhibit at the Smithsonian's National Museum of Natural History. The museum has millions of visitors per year. Our exhibit will include a large display that illustrates the connections among land, ocean, and atmosphere. The exhibit will also include an interactive module that deals with Aura's three main science questions. The Laboratory's Visualization Analysis Laboratory (VAL) will develop the digital interactive displays. The museum will also develop a tool kit that will allow the display to be portable, and thereby, available to other museums in the US and abroad.

NASA/NOAA: Earth Science Electronic Theater 2000

The NASA/NOAA Earth Science Electronic Theater (E-Theater) uses interactive computer-driven displays at near-IMAX size to deliver a powerful tool for promoting Earth science. Scientists from the various Earth science disciplines work directly with the Visualization Analysis Laboratory (VAL) team to develop scientifically accurate visualizations. The E-Theater takes on new dimensions each time another scientist speaks to imagery designed and assembled in support of their area of expertise. E-Theater visualizations are rendered at High Definition TV (HDTV) quality, the highest resolution possible. The visualizations can be used in a host of other applications (i.e. National Television Standards Committee (NTSC) TV, QuickTime movies, Web graphics, etc.). QuickTime versions of each E-Theater visualization will be added to the E-Theater Web page (http://Etheater.gsfc.nasa.gov/index.html/) along with an explanation of the scientific significance and the origin of the data.

Using advanced computer technology and a large, panoramic projection screen, the E-Theater allows the presenter to interactively manipulate imagery and data animations. The impressive scale achieved by the wide E-Theater display contributes to a unique audience experience. Furthermore, these unique capabilities allow for spontaneous speaker/audience interactions.

Visualizations produced by our Laboratory's VAL, as well as other Goddard and NASA groups using NASA, NOAA, ESA, and NASDA Earth science data sets continue to be shown around the world using new display technologies. The Electronic Theater has been presented at universities, high schools, museums, and government laboratories to scientists and the general public. The E-Theater traveled to South Africa in support of the Safari 2000 Terra ground-truth experiment. In October, the E-Theater made a tour of New Zealand, Australia, and numerous other countries.

We continue to demonstrate methods for visualizing and interpreting immense HyperImage remote-sensing data sets and 3-dimensional numerical models. We call the data from many new Earth-sensing satellites: *HyperImage* data sets, because they have such high resolution in the spectral, temporal, and spatial domains. The traditional numerical spreadsheet paradigm has been extended to develop a scientific visualization approach for interactively processing HyperImage data sets and 3-D models. The advantages of extending the powerful spreadsheet style of computation to multiple sets of images and organizing image processing were demonstrated using the Distributed Image SpreadSheet (DISS). The DISS is being used as a high performance testbed application for the Next Generation Internet (NGI).

Museum Support

The Visualization Analysis Laboratory, VAL, actively works with several museums in creating new, innovative Earth science displays. A short list of some of these museums include the Smithsonian's National Museum of Natural History, the National Air and Space Museum, the American Museum of Natural History in NY, the Virginia Science Center, and the Houston Museum of Natural History. In conjunction with large museums, we are developing science presentations that will be made accessible and available to smaller museums.

One successful museum activity is the "Earth Today" exhibit. This exhibit evolved from an earlier Smithsonian exhibit, the "HoloGlobe." The Earth Today is a permanent exhibit in the National Air and Space Museum. It contains all of the original information contained in the "HoloGlobe" exhibit, and it has expanded the focus to include near-real-time data displays. These near-real-time data presently include global cloud cover, global water vapor, sea surface temperature, sea surface temperature anomalies, biosphere, and earthquakes. VAL personnel continue to actively promote advancements in this exhibit. These refinements include improved computer coding; new, high-resolution data sets (such as products from TRMM, TOMS, Terra and in the future, Aqua); a new version of Earth Today that will run on many mid-level PC's; and a version that will run on the Web.

Another effort is "Global Links." Global Links is an exhibition in the planning phase at the Smithsonian National Museum of Natural History. This exhibit will feature the four main Earth science spheres: atmosphere, biosphere, hydrosphere, and geosphere. The exhibit will focus on these different systems and explain what we know about the interdependency and delicate balance among these systems. VAL staff worked closely with the museum and NASA scientists to develop the initial concepts used in this exhibit. VAL personnel continue to work with the museum in refining those concepts. The Global Links exhibit provides the perfect opportunity to develop strong content to explain Earth science concepts.

8. ACKNOWLEDGMENTS

We thank all the Laboratory members whose work motivates this report and generates its substance. We especially thank the Branch Heads and Branch Secretaries for helping to gather and write some of the text.

We'd also like to thank Don Swenholt for his counsel on the tone and organization and for his work in editing the many contributions of a variety of authors. We thank Bill Welsh for designing the cover.

Laura Rumburg turned her keen proofreader's eyes on our copy. In addition to the normal proofreading function, Laura diligently researched, edited, and checked factual items, figures, and tables.

The final formatting and layout of the finished product for printing was done by Terri Randall.

Edited by the Code 910 senior staff.

APPENDIX 1. 2000 SHORT-TERM VISITORS

DATA ASSIMILATION OFFICE

Lars Peter Riishojgaard EUMETSAT	January 5-8
Oreste Reale COLA	January 26
Luc Fillion NCAR	January 31-February 5
Stephen Eckermann Naval Research Laboratory	February 18
Kwok Aun Tan Naval Research Laboratory	February 18
David Broutman Naval Research Laboratory	February 18
Olivier Cabanes METEO	February 22-24
Dirceu Luis Herdies CPTEC/INPE	March 1-31
Mokonari Hamasaki Columbia University	March 20
Ryosuke Nisimura Columbia University	March 20
Tositaka Hokazono Columbia University	March 20
Olivier Cabanes METEO	March 22-24
Daniel Kirk-Davidoff Harvard University	March 23-24
Michael Navon Florida State University	March 27-29
Olivier Cabanes METEO	March 28-30
Robert Ogglesby Purdue University	March 29-30
Chris Ding Lawrence Berkeley Labs	March 29
Tsann Wang Yu NOAA/National Weather Service	March 31-September 30
Luc Fillion NCAR	April 2-8
T.N. Krishnamurti Florida State University	April 4
Prasad Kasibhatla Duke University	April 5
Carolyn Jordan Duke University	April 5
Daniel Jacob Duke University	April 5
Paul Palmer Harvard University	April 5
Jennifer Logan Harvard University	April 5
Bryan Duncan Harvard University	April 5
Bob Yantosca Duke University	April 5
Richard Menard McGill University	May 3-23
Richard Lindzen MIT	May 22-25
Rick Lawford NOAA OGP	May 25, June 13
Haroldo Campos Velho National Institute for Space Research	June 1-2
Noah Wolfson Meteo-Tech Ltd.	June 12-27
Jiun-Dar Chern Purdue University	June 13-15
Byron Boville NCAR	June 19

Vladimir Krasnopolsky
NOAA/NCEP
July 1-October 1

Raymond Arritt
Iowa State University
July 12-14

John MacGregor
SIRO Atmospheric Research
July 21

Chaojiao Sun
UCLA
July 31

Mircea Grecu
University of Connecticut
August 7-18

Noah Wolfson
Meteo-Tech Ltd.
August 10-25

Pinhas Alpert
Tel-Aviv University
August 11

Michael Fiorino
Lawrence Livermore National Laboratory
August 28-31

Hongyu Liu
Harvard University
September 6

Ron Errico
NCAR
September 14

Jean Cote
Canadian Meteorological Center
September 19-22

Richard Goody
Harvard University
September 19-20

Keith Briggs
British Telecommunications Company
October 27

Krzystof Nowak
SUNY
November 21

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Ping Ping Xie
NOAA/NCEP
February 3

Zhimin Qu
SuperOptronics, Inc.
February 14-15

Armin Hansel
University of Innsbruck
March 15

Nicolas F. Viltard
CETP, France
March 27-31
April 3-7
October 30 – November 3

Thomas Nauss
University of Munich, Germany
May 1 – July 1

Gillian Chaplin
Magian Design Studio
May 2

Les Gilbert
Magian Design Studio
May 2

Mircea Grecu
University of Connecticut
June 2, August 6-20

Stephan Rahm
DLR – Oberpfaffenhofen
June 20

Ming-Jen Yang
University of Taipei, Taiwan
June 26-29

Tufa Dinku
University of Connecticut
July 1 – August 6

Christoph Bollig
German Aerospace Research Center (DLR)
July 6-28

Minghu Chen
Chinese Academy of Meteorological Sciences
July 14, July 19

Shu-hua Chen
NCAR/MMM
July 26-28 & 31

Emmanouil Anagnostou
University of Connecticut
August 4

Saswati Datta
JCET
September 28
October 4 & 13

Jose Hernandez
Oak Ridge National Laboratory
October 1 – November 30

Christopher Kidd
University of Birmingham, UK
October 30 – November 3

Daniel Sempere-Torres
Universitat Politecnica de Catalunya (UPC)
November 1-3

Shioichi Shige
Kyoto University
November 1 – February 15, 2001

F. Guichard
Centre National de Research Meteorologiques
November 9

Jean-Luc Redelsperger November 9
Centre National de Research Meteorologiques

Akiyo Yatagai December 11-13
National Space Development Agency of Japan

CLIMATE AND RADIATION BRANCH

Aline Procopio January 4
Federal University, Rio De Janeiro

Kyu-Tae Lee January 4, July 10
National Kangnung University

Yongxiang Hu January 12
NASA Langley Research Center

Jung Moon Yoo January 12, July 3
Ewha Womens' University

John R. Bates January 26
University of Copenhagen

Peter Israelevitch February 7
Tel Aviv University

Edmund Klodzh February 7
Tel Aviv University

Georgiy Stenchikov February 22
Rutgers University

Gu Jie February 28
DSO National Laboratories

Wee-Chin Goh February 28, June 12
DSO National Laboratories

Hong-Hin Kwong February 28, June 12
DSO National Laboratories

Norm Wood March 7
NOAA/CMDL

C. Adam Schlosser March 8
COLA

Jaya Ramaprasad March 10
George Mason University

Kwang-yul Kim March 29
Florida State University

Paulo Artaxo April 17
Universidade de Sao Paulo

Daniel Rosenfeld April 17
The Hebrew University

Xin-Zhong Liang April 25
University of Illinois/Urbana-Champaign

Chidong Zang May 10
University of Miami

Tsung-Hsin Hsieh May 22
Towson University

Brian Ebel (summer student) June 1
NASA Academy

Wen-Yih Sun June 6
Purdue University

Peter Pilewskie June 8
NASA Ames Research Center

Hailey King June 26
SSAI

Louis Gonzalez Alvarez July 17
Universite des Sciences et Technologies de Lille

Grzegorz Jan Ciach July 31
Env. Verif. & Analysis Center

Shane Crothers July 31
University of Virginia

Helene Chepfer August 14
NASA Langley Research Center

Knut W. Dammann August 17
Institute for Atmospheric Physics

Santiago Gasso September 18
University of Washington

Wei-Min Hao September 25
USDA Forest Service

Zhanqing Li September 25
Canada Centre for Remote Sensing

Harshvardhan October 10
Purdue University

Arnon Karnieli November 14
Ben Gurion University

ATMOSPHERIC EXPERIMENT BRANCH

Sushil Atreya
University of Michigan
Various times

Bruce Block
University of Michigan
Various times

John Maurer
University of Michigan
Various times

Toby Owens
University of Hawaii
Various times

Chad Rue
University of Utah
April 17-19

Will Brinckerhoff
John Hopkins University
Applied Physics Lab
June 1

Tim Cornish
John Hopkins University
Applied Physics Lab
June 1

Jess Lewis
University of Maryland
June 1 – Aug 20

Ann Bergquist
Virginia Tech
June 10-Aug 1

Jeff Komives
Purdue University
June 10-Aug 1

Ryan Miller
University of Michigan
July 10-14

Steve Musko
University of Michigan
July 10-14

Doug McCarter
McCarter Technology
October 13

Reza Ghodssi
University of Maryland
November 2

Gary Rubloff
University of Maryland
November 2

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Jun Wu
University of Maryland
January 1-May 15

J. P. Veefkind
KNMI
January 28

Bert van dau Oord
KMNO
January 28

Dr. Richard Anthes
UCAR
February 2-3

Marcos Andrade
University of Maryland
February 4

P. Isrealivitch
Tel Aviv University
February 6-19

E. Klodj
Tel Aviv University
February 6-19

Chris Reading
ESA/ESTEC
February 7

J. Joseph
Tel Aviv University
February 14-19

A. Devir
Tel Aviv University
February 14-19

Y. Noter
Tel Aviv University
February 14-19

L. Ramon
Tel Aviv University
February 14-19

I. Mayo
Tel Aviv University
February 14-19

Jens Reichardt
GKSS Research Center
February 14-25

Fumio Hasebe
Ibaraki University
February 24

Dr. Miguel Rivas Avia
Universidade Tarapaca
March 6-18

Marcos Andrade
University of Maryland
March 23

Ruben Piacentini
University of Rosario
May 7-11

Edgar Crino
University of Rosario
May 7-11

Colin Hines
Toronto, Canada
May 9-13

Kwing Chan
University of Science & Technology
May 17-24

Hayden Porter May 19-26
Furman University

Francoise Posny May 30
University of Reunion Island

Shuji Kawakami May 30
Space Agency of Japan

Masutono Fujiwara May 30
Hokkaido University

Diego Loyola May 30-July 28
DLR

Dave Flittner June 1
University of Arizona

Kostas Kourtidis June 13-27
Aristotle University of Thessaloniki

Michel Claereboudt June 19-21
University of Oman

Jean-Baptiste Marcovici July 3-September 2
Institute National des Telecommunications

Dr. Cheng-Hsuan Lu August 13-24
SUNY-Albany

Alexander Cede August 15-December 15
Institut for Medizinische Physik

John Burrows August 21-30
University of Bremen

Peter Teague August 25
VIPAC Engineers & Scientists

Martin Freitag August 28-September 8
Institute of Environmental Physics

Seong Soo Yuk August 31
Desert Research Institute

Edu van der Noorda September 15
Fokker Space Corporation

Andrew Court September 15
Netherlands Organization and Applied Science

Roel Hokstra September 15
Netherlands Organization and Applied Science

Didier Rault September 29
NASA Langley Research Center

Klaas Folkert Boersma October 2-20
KNMI

Ellen Jeannette Brinksma October 2-20
KNMI

Liisa Oikarinen October 23-24
Finnish Meteorological Institute

Erkki Kyrola October 23-24
Finnish Meteorological Institute

APPENDIX 2. 2000 COMPOSITION OF THE VISITING COMMITTEES FOR THE LABORATORY

LABORATORY VISITING COMMITTEE (OCTOBER 1993)

Alan K. Betts, Chairperson
Atmospheric Research Corporation, Pittsford, VT

Michael Ghil
Department of Atmospheric Science
University of California at Los Angeles, CA

Donald R. Johnson
Space Science and Engineering Center
University of Wisconsin, Madison, WI

Timothy L. Killeen
Space Physics Research Laboratory
University of Michigan, Ann Arbor, MI

Jose M. Rodriguez
AER, Inc., Cambridge, MA

Edward Westwater
CIRES, Boulder, CO

DATA ASSIMILATION OFFICE ADVISORY PANEL (OCTOBER 1992, OCTOBER 1993, JANUARY 1995, JUNE 1996, MAY 1998)

Roger Daley, Chairperson
Naval Research Laboratory, Monterey, CA
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Jeffrey Anderson
GFDL/NOAA
Princeton University, Princeton, NJ
(served Advisory Panel 1995, 1996, 1998)

Andrew F. Bennett
College of Oceanography
Oregon State University, Corvallis, OR
(served Advisory Panel 1995, 1996, 1998)

Guy Brasseur*
National Center for Atmospheric Research, Boulder, CO
(served Advisory Panel 1992, 1993, 1995)

Phillippe Courtier
Laboratoire d'Océanographie Dynamique et de Climatologie (LODYC), Paris, France
(served Advisory Panel 1995, 1996, 1998)

Robert E. Dickinson
Department of Atmospheric Science
University of Arizona, Tucson, AZ
(served Advisory Panel 1995, 1996, 1998)

Anthony Hollingsworth*
European Centre for Medium-Range Weather Forecasts (ECMWF), Reading England
(served Advisory Panel 1992, 1993)

Daniel J. Jacob
Division of Engineering and Applied Science
Harvard University, Cambridge, MA
(served Advisory Panel 1995, 1996, 1998)

Donald R. Johnson
Space Science and Engineering Center
University of Wisconsin, Madison, WI
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Kikuro Miyakoda*
GFDL/NOAA
Department of Commerce
Princeton University, Princeton, NJ
(served Advisory Panel 1992, 1993, 1995)

James J. O'Brien
Professor of Meteorology and Oceanography
Florida State University, Tallahassee, FL
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Alan O'Neill
The Center for Global Atmospheric Modelling
Department of Meteorology
University of Reading, Reading, England
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

DATA ASSIMILATION OFFICE COMPUTER ADVISORY PANEL (MARCH 1996, AUGUST 1997)

William F. Farrell, Chairperson
SAIC, San Diego, CA

Tony Busalacchi
Laboratory for Hydrospheric Processes, Code 970
NASA Goddard Space Flight Center, Greenbelt, MD

Bill Dannevik
L262, Environmental Programs
Lawrence Livermore National Laboratory,
Livermore, CA

Alan Davis
Center for Ocean-Atmosphere Prediction Studies
Florida State University, Tallahassee, FL

Geerd-R. Hoffmann, Head
Computer Division
European Centre for Medium-Range Weather
Forecasts (ECMWF), Reading, England

Menas Kafatos
University Professor of Interdisciplinary Science
Director, Institute for Computational
Sciences and Informatics
George Mason University, Fairfax, VA

Reagan W. Moore
Enabling Technologies Group
San Diego Supercomputer Center, San Diego, CA

John Sloan*
NCAR/SCD, Boulder, CO

Thomas Sterling*
Lawrence Livermore National Laboratory, Livermore, CA

MESOSCALE ATMOSPHERIC PROCESSES BRANCH, EXTERNAL REVIEW COMMITTEE REPORT, NASA GSFC, NOVEMBER 9, 1999

Dr. Robert Gall, Chair
Mesoscale Microscale Meteorology Division
National Center for Atmospheric Research
Boulder, CO

Dr. Michael Hardesty
Environmental Technology Laboratory
National Oceanic and Atmospheric Administration
Boulder, CO

Dr. Frank Marks
Hurricane Research Division
National Oceanic and Atmospheric Administration
Miami, FL

Dr. Eric Smith
Department of Meteorology
Florida State University
Tallahassee, FL

EDGE TECHNIQUE REVIEW COMMITTEE, NASA GSFC AUGUST 6-7, 1997

R. Michael Hardesty (Chair)
NOAA ERL, Boulder, CO

Edwin Eloranta
University of Wisconsin, Madison, WI

Chester Gardner
University of Illinois, Urbana, IL

Robert Menzies
NASA Jet Propulsion Laboratory, Pasadena, CA

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH, NASA GSFC, BLDG. 21, ROOM 183, APRIL 16-18, 1997

Dr. William L. Chameides
School of Earth and Atmospheric Sciences
Georgia Institute of Technology, Atlanta, GA

Douglas D. Davis
School of Geophysical Science
Georgia Institute of Technology, Atlanta, GA

Matthew H. Hitchman
Dept. of Atmospheric and Oceanic Sciences
University of Wisconsin, Madison, WI

David J. Hoffman
Climate Monitoring and Diagnostics Laboratory
National Oceanic and Atmospheric Administration,
Boulder, CO

Susan Solomon
Environmental Research Laboratory
National Oceanic and Atmospheric Administration,
Boulder, CO

Joe W. Waters
Microwave Atmospheric Science Group
NASA Jet Propulsion Laboratory, Pasadena, CA

* *No longer on the committee*

APPENDIX 3. 2000 VISITING SCIENTISTS AND ASSOCIATES OF JOINT CENTERS

CCAST (UNIVERSITY OF ARIZONA)

Robert Loughman
Liming Xu

DISTINGUISHED VISITING SCIENTIST

David Atlas

DOE

David Erickson
Jose Hernandez

ESSIC

David Considine
Andrew Dessler
Michael Fox-Rabinovitz
Peter Lyster
Vikram Mehta
Kenneth Pickering
Maria Tzortziou
Zihou Wang
Michael Yeh

GEORGE MASON UNIVERSITY

Dave Augustine
Bart Kelley
Mark Kulie
David Marks
Michael Robinson
David Silberstein

GEORGIA TECH.

Mian Chin
Paul Ginoux

GEST CENTER

Jiun-Dar Chern
Dirceu Luis Herdies
Nickolay Krotkov
Redgie Lancaster
Ruei-Fong Lin
Ashwin Mahesh
Peter Norris
Steven Pawson
Zhaoxia Pu
Anil Rao
Steve Sherwood
Lin Tian
Clark J. Weaver
Judd Welton

HOWARD UNIVERSITY

Vernon Morris

JCET

Eyal Amitai
Scott Curtis
Belay Demoz
Keith Evans
Jeffrey Halverson
Scott Janz
Yong Li
Alexander Marshak
Jose Vanderlei Martins
Amita Mehta
William Olson
Lazaros Oraiopoulos
Steven Platnick
Paul Poli
Jens Reichardt
Thomas Rickenbach
Lars Peter Riishojgaard
Alexander Sinyuk
Lynn Sparling
Andrew Tangborn
Ali Tokay
Omar Torres
Tamas Varnai
J. J. Wang
Yansen Wang
Guoyong Wen
Song Yang

JOHNS HOPKINS UNIVERSITY

Donald Anderson
Albert Arking

LAOR

Joe Otterman

NRC

Anna Rozwadowska
Sam Shen

NSF
Sankar-Rao Mopidevi

TEL AVIV UNIVERSITY
Prof. Pinhas Alpert
Prof. Zev Levin

UCLA
Ning Zeng

URF
Liela Garcia
Willis Wilson

USRA
Julio Bacmeister
Pui King Chan
Baode Chen
Frank Evans
Rosana Nieto Ferreira
Charles Gatebe
Kyu-Myong Kim
Kyu-Tae Lee
Ruei Fong Lin
Po-Hsiung Lin
Annarita Mariotti
Didier Tanre

APPENDIX 4. 2000 SEMINARS

LABORATORY FOR ATMOSPHERES SEMINAR SERIES

Professor Graeme Stephens, Colorado State University, "The A-Band Approach to Aerosol and Cloud Properties," January 4.

Dr. Richard Menard, University of Maryland Baltimore County, "Assimilation of Chemical Tracer Observations," January 18.

Dr. Gerald M. Heymsfield, NASA Goddard Space Flight Center, "Studies of Convective Systems and Hurricanes Using ER-2 Doppler Radar," February 1.

Dr. Paul R. Mahaffy, NASA Goddard Space Flight Center, "The Atmosphere of Jupiter - 4 Years After the Galileo Entry Probe," February 15.

Dr. Lorraine A. Remer, NASA Goddard Space Flight Center, "Principles of Remote Sensing of Aerosol from MODIS," March 7.

Dr. William J. Randel, National Center for Atmospheric Research (NCAR), "Low-frequency Global Variations of Stratospheric NO_2," March 21.

Dr. Joanna Joiner, NASA Goddard Space Flight Center, "Improving the Use of Passive Microwave and Infrared Sounding Information in the GEOS-DAS," April 4.

Dr. James W. Hurrell, National Center for Atmospheric Research (NCAR), "On the Annual Cycle of Climate Change Over the Atlantic," April 18.

Dr. Paul A. Newman, NASA Goddard Space Flight Center, "The SAGE III Ozone Loss and Validation Experiment," May 2.

Dr. William K. Lau, NASA Goddard Space Flight Center, "An Assessment of Regional Climate Anomalies of the 1997-98 El Niño," May 16.

Professor Michael Montgomery, Colorado State University, "Vortex Rossby Waves and Hurricane Dynamics," September 13.

Professor Richard Goody, Harvard University, "Global Climate Benchmarks: Data to Test Climate Models," September 19.

Dr. William K. Lau, NASA Goddard Space Flight Center, "An Assessment of Regional Climate Anomalies of the 1997-98 El Niño," October 3.

Dr. Si-Chee Tsay, NASA Goddard Space Flight Center, "Absorption of Solar Radiation by Clouds: A Second Look at Irradiance Measurements," October 17.

Dr. David H. Rind, NASA Goddard Institute for Space Studies, "Effect of (Various) Climate Changes on the Stratosphere," November 7.

Dr. Jian-Wen Bao, NOAA/ETL, "Numerical Simulation of Air-Sea Interaction Under High Wind Conditions," November 21.

Dr. Edward C. De Fabo, George Washington University, "Potential Impacts on Human Health and the Biosphere From Increased UV-b Radiation Associated with Stratospheric Ozone Depletion," December 5.

Dr. Warwick Norton, Oxford University, "Dynamics and Tracer Transport in the Tropical Lower Stratosphere," December 11.

DATA ASSIMILATION OFFICE

Daniel Kirk-Davidoff, Harvard University, "Tropical Dynamics, Water Vapor, and Upper Troposphere," March 24.

Chris Ding, Lawrence Berkeley Labs, "Using Accurate Arithmetics to Improve Numerical Reproducibility and Stability in Parallel Applications," March 29.

Rolf Reichle, Massachusetts Institute of Technology, "Variational Assimilation of Microwave Radiobrightness Observations for Land Surface Hydrologic Applications," September 5.

Ron Errico, NCAR, "Continuing research on the assimilation of precipitation data," September 14.

Brian Doty, COLA, "GrADS to use DODS servers," September 19.

Richard Goody, Harvard University, "Global Climate Benchmarks: Data to test Climate Models," September 19.

Fekadu Moreda, University of Oklahoma, "Natural Hazards Prediction Using Remote Sensing: Floods, Drought, and Water Quality," October 2.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Yvette P. Richardson, University of Oklahoma, "The Influence of Horizontal Variations in Vertical Shear and Low-Level Moisture on Numerically-Simulated Convective Storms," March 13.

Roger Pielke, Colorado State University, "The Role of Land Surface Processes in Cumulus Convective Rainfall-Implications for Weather and Climate," March 30.

Adam H. Sobel, Columbia University, "Modeling Tropical Precipitation in a Single Column," April 3.

T. N. Krishnamurti, Florida State University, "Superensemble Based Skills of Assimilation and Forecasts using TRMM/SSMI Rainrates," April 4.

F. Martin Ralph, NOAA/Environmental Technology Laboratory, "The West Coast Forecast Challenge: Bridging Research and Operations in the CALJET and PACJET Experiments," April 19.

Larry Belcher, Jr., Colorado State University, "Classification of Tropical Precipitation Regimes: A Comparative Analysis of Disdrometer, Profiler, and Multiparameter Radar Measurements," April 25.

Michael Schonhuber, Joanneum Research, Graz, Austria, "Application of the 2D-Video-Distrometer for Remote Sensing and Telecommunication Purposes," May 1.

Joel Tenenbaum, SUNY Purchase, "Informal Report on the EUCOS Experiment, the Christmas 1999 European Storms and the Effects of Automated Aircraft Reports," May 4.

Ming-Jen Yang, Chinese Culture University, "Microphysics and Boundary-Layer Parameterizations in a Simulated Oceanic Convective System," June 26.

Cheng Minghu, Chinese Academy of Meteorological Sciences, "Observations of Heavy Rainfall Events over China using TRMM Data," July 19.

Edward A. Brandes, National Center for Atmospheric Research (NCAR), "Rainfall Estimation with Polarimetric Radar: An Update," July 25.

Jose D. Fuentes, University of Virginia, "Atmospheric Boundary Layer Dynamics and Associated Entrainment Rates of Heat and Water Vapor over a Pasture Site in Amazonia," July 31.

Emmanouil Anagnostou, University of Connecticut, "Satellite Passive Microwave Precipitation Estimation – Relations Evaluated from TRMM Multi-Sensor Precipitation Profile Retrievals," August 4.

Courtney Schumacher, University of Washington, "Kwajalein, the TRMM PR, and Convective-Stratiform Mapping over the Tropics," August 18.

Alexander Khain, The Hebrew University of Jerusalem, "Simulation of Deep Convective Clouds in Clear and Smoky Air," August 25.

Walter Petersen and Robert Cifelli, Colorado State University, "Analysis of TRMM-LBA Convection: A Multi-Scale Perspective," August 28.

Ron Errico, NCAR, "Continuing Research on the Assimilation of Precipitation Data," September 14.

Jeff Hawkins, Naval Research Laboratory, "Tropical Cyclone Structure Via Multiple Passive Microwave Satellite Sensors," October 5.

Kurt Brueske, USAF/University of Wisconsin-Madison and Chris Velden, University of Wisconsin-Madison (CIMSS), "Estimating Tropical Cyclone Intensity Using the NOAA-KLM Advanced Microwave Sounding Unit (AMSU)," October 16.

Robert Tuleya, GFDL/NOAA, "Hurricane Landfall: From a Modeller's Perspective," October 17.

Jean-Luc Redelsperger, NCRS & Meteo-France Joint Laboratory, "Recent Results on the Effects of Tropical Convection on Surface, Ocean and Atmosphere," November 9.

CLIMATE AND RADIATION BRANCH

Yongxiang Hu, NASA Langley Research Center, "Cloud Spatial Correlation Length and its Impact on Anisotropy of Radiances," January 12.

John Ray Bates, Danish Center for Earth System Science, Niels Bohr Institute for Astronomy, "A Dynamical Stabilizer in the Climate System: a Mechanism Suggested by a Simple Model and Supported by GM Experiments," January 27.

Albert Arking, Johns Hopkins University, "The Discrepancy Between Theory and Measurement of Atmospheric Absorption of Solar Radiation and its Impact on Climate Models," February 9.

Georgiy Stenchikov, Rutgers-The State University of NJ, "GCM Simulation of Climate Impact of the 1991 Mt. Pinatubo Eruption," February 23.

C. Adam Schlosser, COLA, "The Potential Impact of Soil Moisture Initialization on Soil-Moisture Predictability and Associated Climate Predictability," March 8.

Brent Holben, NASA GSFC, Biospheric Sciences Branch, "Sun Photometry Networks Past, Present and Future," March 22.

Kwang-Yul Kim, Florida State University, Department of Meteorology, "Surface and Subsurface Variability in the Tropical Pacific Investigated by Cyclostationary EOF Analysis," March 31.

Winston C. Chao, NASA GSFC, Climate & Radiation Branch, "Some Characteristics of the ITCZ," April 12.

Daniel Rosenfeld, Institute of Earth Sciences, The Hebrew University of Jerusalem, "Satellite (TRMM & AVHRR) Measurements of the Impact of Smoke and Regional Pollution on Precipitation," April 17.

Teruyuki Nakajima, Center for Climate System Research, the University of Tokyo, "A Study of Aerosol and Cloud Interaction Phenomenon Using Satellite Remote Sensing and Climate Modelling," April 17.

Xin-Zhong Liang, Illinois State Water Survey, University of Illinois at Urbana-Champaign, "Development of Regional Climate Model for Midwest Applications," April 26.

Chidong Zhang, University of Miami, Rosenstiel School of Marine & Atmospheric Science, "The Bimodality of Tropical upper-Tropospheric Water Vapor: Observations from In-situ and Remote Sensing Measurements," May 10.

Jose Vanderlei Martins, UMBC/JCET, Climate & Radiation Branch, "The Effects of Aerosol Particles in Amazonia: Biogenic versus Biomass Burning Particles," May 24.

Peter Pilewskie, NASA Ames Research Center, "A Moderate Resolution View of the Solar Spectrum in Earth's Atmosphere," June 8.

Siegfried Schubert, NASA GSFC, Data Assimilation Office, "The Seasonal Prediction Problem," June 16.

Pinhas Alpert, Tel Aviv University, "Dust Prediction at Tel Aviv University," August 11.

Knut Dammann, Institute for Atmospheric Physics, GKSS Research Centre, "Aerosol Impact on the Earth Radiation Budget with Satellite Data in Support of the Geostationary Earth Radiation Budget (GERB) Experiment," August 17.

Ming-Dah Chou, NASA GSFC, Climate & Radiation Branch, "Clouds, Radiation Budgets, and Climate as Inferred From Japanese GMS-5 Measurements," September 27.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Wenhan Qin, NASA GSFC/Raytheon, "Hotspot Effect: Modeling and Application," April 26-28.

Xiao Bao Fan, University of Maryland, "Distribution Of Carbon Monoxide In The GOCART Model," July 27.

Dr. Seong-Soo Yum, Desert Research Institute, "Contrasts In Cloud Microphysics Between Continental and Maritime Warm Clouds," August 31.

Dr. Lawrence Coy, NASA GSFC/General Sciences Corporation, "Issues Regarding the Quality of DAO Analyses in the Middle Atmosphere: GEOS-3 And FVDAS," October 20.

Dr. Andrew Dessler, NASA GSFC/ESSIC, "Tracer Correlations In The Tropopause Layer," October 27.

Dr. Steven Sherwood, NASA GSFC/University Space Research Associates, "Evidence Of Rapid Dehydration And Mixing Within A Tropopause Layer," November 3.

Dr. Steven Pawson, NASA GSFC/University Space Research Associates, "Model Study Of The Sources Of Upper Tropospheric Ozone Over The Atlantic, With Emphasis On Interhemispheric Asymmetries," December 1.

Dr. Stephan Kawa, NASA GSFC, "Simulating Observed Ozone Loss In The Northern Hemisphere Winter," December 1.

APPENDIX 5. 2000 SCIENCE TEAM MEETINGS AND WORKSHOPS

SCIENCE POLICY MEETINGS

National Academy of Sciences/National Research Council Committee. Dr. Rood (910.3) served on the committee writing a report on improving the effectiveness of U.S. climate modeling.

Office of Science and Technology Policy, OSTP, Dr. Rood (910.3) was detailed to NASA HQ and OSTP to develop strategic approaches to high-end modeling and supercomputing. OSTP requested him to appoint an interagency team to write a report to serve as a foundation to develop a national approach to addressing shortcomings in the U.S. ability to deliver needed climate model and data products. The report "High End Climate Science: Development of Modeling and Related Computing Capabilities," has been released and is available on http://www.usgcrp.gov/ under "What's new." Other panel members were Jeff Anderson (GFDL), Dave Bader (DOE), Maurice Blackmon (NCAR), Tim Hogan (DOD), Pat Esborg (Organizational Consultant). The report was presented to OSTP on August 25. Dr. Rood briefed Neal Lane, Assistant to the President for Science and Technology, on climate modeling and its related supercomputing on August 11.

Dr. Sud was invited to the White House to attend the First High Level Round Table Meeting with the Indian Delegation for Indo-US collaboration on September 17.

SCIENCE TEAM MEETINGS

Laboratory for Atmospheres

SOLVE Theseo 2000 Science Meeting, 25-29 September, Palermo, Italy.

Sounder Research Team

IPO SOAT Meeting, Silver Spring, Maryland, February 3.

AIRS Science Team Meeting, Arcadia, California, February 10-11.

Sponsored AIRS Programming and Validation Team Meeting, March 1-2, at Goddard.

IPO SOAT Meeting, Silver Spring, Maryland, June 6.

AIRS Science Team Meeting, Baltimore, Maryland, June 20-22.

International Radiation Symposium, St. Petersburg, Russia, July 21-30.

AIRS Science Team Meeting, Pasadena, California, October 3-5.

IPO SOAT Meeting, Silver Spring, Maryland, October 12.

AGU Fall Meeting, San Francisco, California, December 14-20.

Data Assimilation Office

Advisory Board Meeting, Tropical Atmospheric Science Center (TASC), University of Puerto Rico, March 4-8.

AGU Spring Meeting, Washington, DC, May 31, invited speaker.

Program Committee Member, 4th International Symposium on Gas Transfer at Water Surfaces, Miami, Florida, June 5-8.

United Nations Environment Program (UNEP), Invited author for effects section on "Increased UVB fluxes and global biogeochemical cycles," Abisko, Sweden, August 21-26.

Member, NASA Oceanography/air-sea exchange review panel, Pentagon City, Arlington, Virginia, September 26.

Mesoscale Atmospheric Processes Branch

13th International Conference on Clouds and Precipitation, Reno, NV, August 14-18, Organizing Committee and Session Chair.

TRMM U.S. Science Team Meeting, October 30-November 2, at the Greenbelt Marriott.

AGU Fall Meeting, San Francisco, California, December 14-20, convener: special session on "Convective Systems observed during TRMM Field Campaigns (2000)."

Climate and Radiation Branch

European Geophysical Society 2000, April 19-May 1, Nice France, Convener: Robert F. Cahalan.

AGU Spring Meeting, Washington, DC, May 31, Washington, DC, Co-Convener on Early Terra Results: Yoram J. Kaufman.

Committee on Space Research (COSPAR) 2000 Meeting, June 29-July 19, Warsaw, Poland, Co-Convener on Early Terra Results: Yoram J. Kaufman.

International Geoscience and Remote Sensing Symposium (IGARSS) Meeting, July 21-31, Maui, Hawaii, Co-Convener on Early Terra Results: Yoram J. Kaufman.

International Conference on Clouds and Precipitation, August 13-19, Reno, Nevada, Organizer/Executive Committee: David O'C. Starr.

Cloud and Radiation Group Retreat, August 6-12, NASA Wallops Flight Facility, Organizer: Warren Wiscombe.

SORCE Science Team Meeting, September 13-16, Snowmass Colorado, Co-Organizer: Robert F. Cahalan.

Science Working Group of the AM Platform (SWAMP) Meeting, September 5-7, Toronto, Canada, Terra Project Convener: Yoram J. Kaufman.

Atmospheric Chemistry and Dynamics Branch

NASA ESE-06 Training Program for Satellite Mission Design, April 10-14, Coordinator for ESE planning Aura Cal/Val Integration with Research-Oriented Field Missions in the Next Decade.

NASA AEAP annual meeting, June 5-9, Snowmass, CO.

TOMS Science Team Meeting, May 3-5, Huntsville, Alabama, 30 attendees, P. K. Bhartia, Chair.

AGU Spring Meeting, Washington, DC, May 31.

SPARC meeting, November, Mar del Plata, Argentina and presenting paper.

Aura/OMI Science Meeting - June 13-15, DeBilt, the Netherlands.

SOLVE Theseo 2000 Science Meeting, 25-29 September, Palermo, Italy.

OMI Algorithm Team Meeting - October 2-4, Lanham, MD.

Aura Science Validation Team Meeting - October 16-18, Easton MD.

AGU Fall Meeting, San Francisco, California, December 14-20, session chairman.

Program Committee for SPIE Asia-Pacific Conference on Remote Sensing of the Atmosphere, Environment and Space, October 9-12, Sendai, Japan.

WORKSHOPS

Sounder Research Team

AIRS Science Team Workshop, Pasadena, California, February 7-9.

Data Assimilation Office

Air-sea Interaction Workshop, Tropical Atmospheric Science Center, July 31-August 3, University of Puerto Rico, La Parguera, Puerto Rico.

United Nations Environment Program (UNEP), effects section on 'Increased UVB fluxes and global biogeochemical cycles', August 21-26, Abisko, Sweden, invited author.

DAO/TRACE-P Workshop, September 7, Gi-Kong Kim, Chair.

Mesoscale Atmospheric Processes Branch

Joint Workshop of the GCSS Working Group on Cirrus Cloud Systems and the GCSS Working Group on Extratropical Layer Cloud Systems, July 17-21, U.K. Meteorological College, Reading, UK, organized and co-chaired workshop.

Climate and Radiation Branch

7th US-Japan Workshop on Global Change and Precipitation, March 3-11, Tokyo, Japan, Convenor: William K. Lau.

EOS Terra Validation Program/EOS Investigator Working Group Meeting, April 10-13, Tucson, Arizona, Organizer: David O'C. Starr.

Third GCSS International Cirrus Cloud Modeling Workshop (joint with GCSS Extratropical Layer Cloud Systems Workshop), July 14-22, Reading, United Kingdom, Organizer and Chairman: David O'C. Starr.

Workshop on Relationships and Intercomparison of Monsoon Climate Systems, November 28-30, NASA Goddard Space Flight Center, Convenor: William K. Lau.

Intercomparison of 3-Dimensional (3D) Radiation Codes (I3RC-2000) Workshop, November 14-19, Tucson Arizona, Organizer and Convener: Robert F. Cahalan.

Atmospheric Chemistry and Dynamics Branch

EOS Aura OMI Algorithm Working group. October 2-4. Raytheon ITSS office Greenbelt. MD.

WMO Dobson Intercomparison Workshop, March 25-April 5. Pretoria, South Africa.

APPENDIX 6. 2000 NASA TECHNICAL MEMORANDA AND OTHER PUBLICATIONS

SOUNDER RESEARCH TEAM

Susskind, J., Barnet, C.D., and Blaisdell, J., "Determination of atmospheric and surface parameters from AIRS/AMSU/HSB data in IRS-2000: Current Problems in Atmospheric Radiation," A. Deepak Publishing, Hampton, Virginia, August.

DATA ASSIMILATION OFFICE

Lyster, P., "Final Report", NASA Grand Challenge Applications and Enabling Scalable Computing Testbed in Support of High Performance Computing. PI Project: Four Dimensional Data Assimilation.

CLIMATE AND RADIATION BRANCH

David Herring edits materials before publication on the Terra home page, http://terra.nasa.gov/ and the Earth Observatory (updated daily), http://earthobservatory.nasa.gov/.

Michael King and David Herring, "Monitoring Earth's Vital Signs," an article on Terra in the April 2000 issue of *Scientific American*.

Michael King and David Herring wrote an overview paper on the EOS Project submitted to *Physics Today*, and an overview article on Earth Observation from space that was accepted for publication in the forthcoming *Encyclopedia of Astronomy and Astrophysics*.

APPENDIX 7. 2000 REFEREED PUBLICATIONS

LABORATORY FOR ATMOSPHERES

Adler, R., G. Huffman, D. Bolvin, S. Curtis, and E. Nelkin. 2000: Tropical rainfall distributions determined using TRMM combined with other satellite and raingauge information. *J. Appl. Meteor.*, 39, 2007-2023.

Schoeberl, M. R., L. C. Sparling, C. H. Jackman and E. L. Fleming. A lagrangian view of stratospheric trace gas distributions. *J. Geophys. Res.*, 105, 1537-1552.

Schoeberl, M. R. and G. A. Morris. A lagrangian simulation of supersonic and subsonic aircraft exhaust emissions. *J. Geophys. Res.*, 105, 11,833-11,839.

SOUNDER RESEARCH TEAM

Anyamba, E., E. Williams, J. Susskind, A. Fraser-Smith and M. Fullekrug. The manifestation of the madden-julian oscillation in global deep convection and in the schumann resonance intensity. *J. Atmos. Sci.*, 57, 1029-1044.

Anyamba, E. K. and J. Susskind, Evidence of lunar phase influence on global surface air temperature. *Geophys. Res. Lett.*, 27, 2969-2972.

Barnet, C., J. M. Blaisdell and J. Susskind, Practical methods for rapid and accurate computation of interferometric spectra for remote sensing applications. *IEEE Transactions on Geoscience and Remote Sensing*, 38, 168-183.

Lakshmi, V. and J. Susskind, Comparison of TOVS-derived land surface variables with ground observations. *J. Geophys. Res.-Atmos.*, 105, 2179-2190.

DATA ASSIMILATION OFFICE

Atlas, R. and R. N. Hoffman, The use of satellite surface wind data to improve weather analysis and forecasting at the NASA Data Assimilation Office. *Satellites, Oceanography and Society*, 57-78.

Chang, Y., S. D. Schubert and M. J. Suarez, Boreal winter predictions with the GEOS-2 GCM: The role of boundary forcing and initial conditions. *Quart. J. Roy. Meteor. Soc.*, 126, 2293-2321.

Dee, D. P. and R. Todling, Data assimilation in the presence of forecast bias: The GEOS moisture analysis. *Mon. Wea. Rev.*, 128, 3268-3282.

Durkee, P. A., K. E. Nielsen, P. J. Smith, P. B. Russell, B. Schmid, J. M. Livingston, B. N. Holben, C. Tomasi, V. Vitale, D. Collins, R. C. Flagan, J. H. Seinfeld, K. J. Noone, E. Ostrom, S. Gasso, D. Hegg and L. M. Russell, Regional aerosol optical depth characteristics from satellite observations: ACE-1, TARFOX and ACE-2 results. *Tellus Series B-Chemical and Physical Meteorology*, 52, 484-497.

Erickson, D. J. III, R. Zepp and R. Atlas, Ozone depletion and the air-sea exchange of greenhouse and climate reactive gases. *Chemosphere - Global Change Science*, 137-149.

Flesia, C., C. L. Korb and C. Hirt, Double-edge molecular measurement of lidar wind profiles at 355 nm. *Optics Letters*, 25, 1466-1468.

Fox-Rabinovitz, M., G. L. Stenchikov, M. J. Suarez, L. L. Takacs and R. C. Govindaraju, A uniform- and variable-resolution stretched-grid GCM dynamical core with realistic orography. *Mon. Wea. Rev.*, 128, 1883-1898.

Fox-Rabinovitz, M. S., Simulation of anomalous regional climate events with a variable-resolution stretched-grid GCM. *J. Geophys. Res.*, 105, 29,635-29,645.

Gentry, B. M., H. L. Chen and S. X. Li, Wind measurements with 355-nm molecular doppler lidar. *Optics Letters*, 25, 1231-1233.

Hou, A. Y., D. V. Ledvina, A. M. da Silva, S. Q. Zhang, J. Joiner and R. M. Atlas, Assimilation of SSM/I-derived surface rainfall and total precipitable water for improving the GEOS analysis for climate studies. *Mon. Wea. Rev.*, 128, 509-537.

Hou, A.Y., S.Q. Ahang, A.M. da Silva, and W. Olson, Improving assimilated global data sets using TMI rainfall and columnar moisture observations, *J. Climate*, 13, 4180-4195.

Joiner, J. and D. Dee, An error analysis of radiance and suboptimal retrieval assimilation. *Quart. J. Roy. Meteor. Soc.*, 126, 1495-1514.

Joiner, J. and L. Rokke, Variational cloud-clearing with TOVS data. *Quart. J. Roy. Meteor. Soc.*, 126, 725-748.

Kodera, K., Y. Kuroda and S. Pawson, Stratospheric sudden warmings and slowly propagating zonal-mean zonal wind anomalies. *J. Geophys. Res.*, 105, 12,351-12,359.

Li, Y., J. Ruge, J. R. Bates and A. Brandt, A proposed adiabatic formulation of 3-dimensional global atmospheric models based on potential vorticity. *Tellus*, 52A, 129-139.

Menard, R., S. E. Cohn, L.-P. Chang and P. M. Lyster, Assimilation of stratospheric chemical tracer observations using a kalman filter. Part I: Formulation. *Mon. Wea. Rev.*, 128, 2654-2671.

Menard, R. and L.-P. Chang, Assimilation of stratospheric chemical tracer observations using a kalman filter. Part II: X-Squared validated results and analysis of variance and correlation dynamics. *Mon. Wea. Rev.*, 128, 2671-2685.

Otterman, J., J. Ardizzone, R. Atlas, H. Hu, J.C. Jusem and D. Starr, Winter-to-spring transition in Europe 48-54° N: From temperature control by advection to control by isolation. *Geophys. Res. Lett.*, 27, 561-564.

Otterman, J., R. Atlas, J. Ardizzone, T. Brakke, S.-H. Chou, J. C. Jusem, M. Glantz, J. Rogers, Y. Sud, J. Susskind, D. Starr and J. Terry, Extreme winter/early-spring temperature anomalies in central Europe. *Research Reports Yagellonian University*, 15, 193-200.

Omidvar, K., Electron capture into Rydberg States according to the born approximation: Correction of an error. *Phys. Rev. A*, 61, 064701.

Pawson, S., K. Kodera, K. Hamilton, T. G. Shepherd, S. R. Beagley, B. A. Boville, J. D. Farrara, T. D. A. Fairlie, A. Kitoh, W. A. Lahoz, U. Langematz, E. Manzini, D. H. Rind, A. A. Scaife, K. Shibata, P. Simon, R. Swinbank, L. Takacs, R. J. Wilson, J. A. Al-Saadi, M. Amodei, M. Chiba, L. Coy, J. de Grandpré, R. S. Eckman, M. Fiorino, W. L. Grose, H. Koide, J. N. Koshyk, D. Li, J. Lerner, J. D. Mahlman, N. A. McFarlane, C. R. Mechoso, A. Molod, A. O'Neill, R. B. Pierce, W. J. Randel, R. B. Rood and F. Wu, The GCM-reality intercomparison project for SPARC (GRIPS): Scientific issues and initial results. *Bull. Amer. Meteor. Soc.*, 81, 781-796.

Riishojgaard, L. P., A method for estimating the analysis error variance in a physical space data assimilation system. *Quart. J. Roy. Meteor. Soc.*, 126, 1367-1385.

Riishojgaard, L. P., I. Stajner and G. P. Lou, The GEOS ozone data assimilation system. *Rem. Sens. Appl.: Earth, Atmos. and Oceans*, 25, 1063-1072.

Rood, R. B., A. R. Douglass, M. C. Cerniglia, L. C. Sparling and J. E. Nielsen, Seasonal variability of middle-latitude ozone in the lowermost stratosphere derived from probability distribution functions. *J. Geophys. Res.*, 105, 17,793-17,805.

Scaife, A. A., J. Austin, N. Butchart, S. Pawson, M. Keil, J. Nash and I. N. James, Seasonal and interannual variability of the stratosphere diagnosed from UKMO TOVS analyses. *Quart. J. Roy. Meteor. Soc.*, 126, 2585-2604.

Shay-El, Y., P. Alpert and A. da Silva, Preliminary estimation of horizontal fluxes of cloud liquid water in relation to subtropical moisture budget studies employing ISCCP, SSMI and GEOS-1/DAS data sets. *J. Geophys. Res-Atmos.*, 105, 18067-18089.

Shukla, J., J. Anderson, D. Baumhefner, C. Brankovic, Y. Chang, E. Kalnay, L. Marx, T. Palmer, D. Paolino, J. Ploshay, S. Schubert, D. Straus, M. Suarez and J. Tribbia, Dynamical seasonal prediction. *Bull. Amer. Meteor. Soc.*, 81, 2593-2606.

Strahan, S. E., Climatologies of lower stratospheric NO_y and O_3 and correlations with N_2O based on *in situ* observations. *J. Geophys. Res.-Atmos.*, 104, 30,463-30,480.

Tangborn, A. and S. Q. Zhang, Wavelet transform adapted to an approximate kalman filter system. *Appl. Num. Math.*, 33, 307-316.

Thuburn, J. and Y. Li, Numerical simulations of Rossby-Haurwitz waves. *Tellus*, 52A, 181-189.

Tippett, M. K., S. E. Cohn, R. Todling and D. Marchesin, Low-dimensional representation of error covariance. *Tellus*, 52, 533-553.

Tippett, M. K., S. E. Cohn, R. Todling and D. Marchesin, Conditioning of the stable, discrete-time Lyapunov operator. *SIAM*, 22, 56-65.

Verter, F., L. Magnani, E. Dwek and L. J. Rickard, Infrared properties of molecular cirrus. II. Cloud-to-cloud variations in graphite and polycyclic aromatic hydrocarbon content. *Astro. J.*, 536, 831-844.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Ackerman, A. S., O. B. Toon, D. E. Stevens, A. J. Heymsfield, V. Ramanathan and E. J. Welton, Reduction of tropical cloudiness by soot. *Science*, 288, 1042-1047.

Amitai, E., 2000: Systematic variation of observed radar reflectivity-rainfall rate relations in the tropics. *J. Appl. Meteor.*, 39, 2198-2208.

Atlas, D., C. W. Ulbrich, F. D. Marks, R. A. Black, E. Amitai, P. T. Willis and C. E. Samsury, Partitioning tropical oceanic convective and stratiform rains by draft strength. *J. Geophys. Res.-Atmos.*, 105, 2259-2267.

Atlas, D., Millennium perspectives. *Bull. Amer. Meteor. Soc.*, 81, 2224-2225.

Baker, R. D., G. Schubert and P. W. Jones, Convectively generated internal gravity waves in the lower atmosphere of venus. Part I: No wind shear. *J. Atmos. Sci.*, 57, 184-199.

Baker, R. D., G. Schubert and P. W. Jones, Convectively generated internal gravity waves in the lower atmosphere of venus. Part II: Mean wind shear and wave -- mean flow interaction. *J. Atmos. Sci.*, 57, 200-215.

Bauer, P., A. Khain, I. Sednev, R. Meneghini, C. Kummerow, F. Marzano and J. P. V. Poiares Baptista, Combined cloud-microwave radiative transfer modeling of stratiform rainfall. *J. Atmos. Sci.*, 57, 1082-1104.

Baum, B. A. and J. D. Spinhirne, Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS 3. Cloud overlap. *J. Geophys. Res.-Atmos.*, 105, 11793-11804.

Berkoff, T. A., D. N .Whiteman, R. D. Rallison, G. K. Schwemmer, L. Ramos-Izquierdo and H. Plotkin, Remote detection of raman scattering by use of a holographic optical element as a dispersive telescope. *Optics Letters*, 25, 1201-1203.

Chepfer, H., P. H. Flaman, L. Sauvage, P. Goloub, G. Brogniez, J. Spinhirne, M. Lavorato and

J. Pelon, Cirrus cloud properties derived from POLDER-1/ADEOS polarized radiances: First validation using a ground-based lidar network. *J. Appl. Meteor.*, 39, 154-168.

Chou, S.-H., W. Zhao and M.-D. Chou, Surface heat budgets and sea surface temperature in the pacific warm pool during TOGA COARE. *J. Climate*, 13, 634-649.

Curtis, S. and R. Adler, ENSO indices based on patterns of satellite-derived precipitation. *J. Climate*, 13, 2786-2793.

Ferrare, R., S. Ismail, E. Browell, V. Brackett, M. Clayton, S. Kooi, S.H. Melfi, D. Whiteman, G. Schwemmer, K. Evans, P. Russell, J. Livingston, B. Schmid, B. Holben, L. Remer, A. Smirnov, and P. Hobbs, 2000: Comparison of aerosol optical properties and water vapor among ground and airborne lidars and sun photometers during TARFOX. *J. Geophys. Res.-Atmos.*, 105, 9917-9934.

Gabella, M. and E. Amitai, Radar rainfall estimates in an alpine environment using different gage adjustment techniques. *Physics and Chemistry of the Earth. Part B-Hydrology Oceans and Atmosphere.* 25, 927-931.

Geerts, B., G. Heymsfield, L. Tian and J. Halverson, Hurricane Georges' landfall in the Dominican Republic: Detailed airborne doppler radar imagery. *Bull. Amer. Meteor. Soc.*, 81, 999-1018.

Grecu, M., E. N. Anagnostou and R. F. Adler, Assessment of the use of lightning information in satellite infrared rainfall estimation. *J. Hydrometer.*, 1, 211-221.

Hong, Y., J. Haferman, W. Olson and C. Kummerow, Microwave brightness temperatures of tilted convective systems. *J. Appl. Meteor.*, 39, 983-998.

Jameson, A. R. and A. B. Kostinski, The effect of stochastic cloud structure on the icing process. *J. Atmos. Sci.*, 57, 2883-2891.

Jameson, A. R. and A. B. Kostinski, Fluctuation properties of precipitation. Part V: On the distribution of rain rates – theory and observations in clustered rain. *J. Atmos. Sci.*, 57, 373-388.

Kalnay, E., S. K. Park, Z.-X. Pu and J. Gao, Application of the quasi-inverse method to data assimilation. *Mon. Wea. Rev.*, 128, 864-875.

Karyampudi, V. M., S. Palm, J. Reagan, H. Fang, W. Grant, R. Hoff, C. Moulin, H. Pierce, O. Torres, E. Browell and S. Melfi, Validation of the saharan dust plume conceptual model using lidar, meteosat and ecmwf data. *Bull. Amer. Meteor. Soc.*, 80, 1046-1075.

Koivunen, A. C. and A. B. Kostinski, A feasibility of data whitening to improve performance of weather radar. *J. Appl. Meteor.*, 38, 741-749.

Kostinski, A. B. and A. R. Jameson, On the spatial distribution of cloud particles. *J. Atmos. Sci.*, 57, 901-915.

Kostinski, A. B. and A. C. Koivunen, On the condition number of gaussian sample covariance matrices. *IEEE Transactions on Geoscience and Remote Sensing*, 38, 329-332.

Kummerow, C., J. Simpson, O. Thiele, W. Barnes, A.T.C. Chang, E. Stocker R.F. Adler, A. Hou, R. Kakar, F. Wentz, P. Ashcroft, T. Kozu, Y. Hong, K. Okamoto, T. Iguchi, H. Kuroiwa, E. Im, Z. Haddad, G. Huffman, B. Ferrier, W.S. Olson, E. Zipser, E.A. Smith, T.T. Wilheit, G. North, T. Krishnamurti, K. Nakamura, 2000: The Status of the Tropical Rainfall Measuring Mission (TRMM) after Two Years in Orbit. *J. Appl. Meteor.*, 39, 1965-1982.

Lucas, C. L., E. J. Zipser and B. S. Ferrier, Sensitivity of tropical west pacific oceanic squall lines to tropospheric wind and moisture profiles. *J. Atmos. Sci.*, 57, 2351-2373.

Marks, D. A., M. S. Kulie, M. Robinson, D. S. Silberstein, D. B. Wolff, B. S. Ferrier, E. Amitai, B. Fisher, J. Wang, D. Augustine and O. Thiele, Climatological processing and product development for the TRMM Ground Validation Program. *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere*, 25, 871-875.

Negri, A. J., E. N. Anagnostou and R. F. Adler, A 10-year climatology of amazonian rainfall derived from passive microwave satellite observations. *J. Appl. Meteor.*, 39, 42-56.

Peppler, R. A., C. P. Bahrmann, J. C. Barnard, J. R. Campbell, M. D. Cheng, R. A. Ferrare, R. N. Halthore, L. A. Heilman, D. Hlavka, N. S. Laulainen, C. J. Lin, J. A. Ogren, M. R. Poellot, L.

A. Remer, K. Sassen, J. Spinhirne, M. E. Splitt and D. D. Turner, ARM southern great plains site observations of the smoke pall associated with the 1998 central american fires. *Bull. Amer. Meteor. Soc.*, 81, 2563-2592.

Powell, D. M., J. A. Reagan, M. A. Rubio, W. H. Erxleben and J. D. Spinhirne, ACE-2 multiple angle micro-pulse lidar observations from Las Galletas, Tenerife, Canary Islands. *Tellus Series B-Chemical and Physical Meteorology*, 52, 652-661.

Qian, W. and S. Yang. Onset of the regional monsoon over Southeast Asia. *Meteor. and Atmos. Physics*, 75, 29-38.

Rao, P. A. and H. E. Fuelberg, An investigation of convection behind the cape canaveral sea breeze front. *Mon. Wea. Rev.*, 128, 3437-3458.

Redelsperger, J. L., P. R. A. Brown, F. Guichard, C. Hoff, M. Kawasima, S. Lang, T. Montmerle, K. Nakamura, K. Saito, C. Seman, W. K. Tao and L. J. Donner, A GCSS model intercomparison for a tropical squall line observed during TOGA-COARE. I: Cloud-resolving models. *Quart. J. Roy. Meteor. Soc.*, 126, 823-863.

Robinson M., M.S. Kulie, D. Silberstein, D.A. Marks, D.B. Wolff, E. Amitai, B.S. Ferrier, B.L. Fisher, and J. Wang, 2000: Evolving Improvements to TRMM Ground Validation Rainfall Estimates. *Phys. Chem. Earth (B)*, 25, 971-976.

Rodgers, E., W. Olson, J. Halverson, J. Simpson, H. Pierce, 2000: Environmental forcing of Supertyphoon Paka's (1997) latent heat structure. *J. Appl. Meteor.*, 39, 1983-2006.

Rodgers, E. B., R. F. Adler and H. F. Pierce, Contribution of tropical cyclones to the north pacific climatological rainfall as observed from satellites. *J. Appl. Meteor.*, 39, 1658-1678.

Sassen, K., R. P. Benson and J. [illegible]hirne, Tropical cirrus cloud properties derived from TOGA COARE airborne polarizat[illegible] *Geophys. Res. Lett.*, 27, 673-676.

Schmid, B., J. Livingston, P. Russel, P. Durkee, H. H. Jonsson, D. R. Collins, R. C. Flagan, J. H. Seinfeld, S. Gasso, D. A. Hegg, E. Ostrom, K. J. Noone, E. J. Welton, K. J. Voss, H. R. Gordon, P. Formenti and M. O. Andreae, Clear sky closure studies of lower tropospheric aerosol and water vapor during ace-2 using airborne sunphotometer, airborne in-situ, space-borne and ground-based measurements. *Tellus B*, 52, 567-592.

Simpson, J., R. F. Adler, J. B. Halverson, A. J .Negri and H. Pierce, Necrology – Edward B. Rodgers 1939-2000. *Bull. Amer. Meteor. Soc.*, 81, 2236-2237.

Tao, W.-K., R. Adler, S. Braun, F. Einaudi, B. Ferrier, J. Halverson, G. Heymsfield, C. Kummerow, A. Negri and R. Kakar, Summary of a symposium on cloud systems, hurricanes and TRMM: Celebration of Dr. Joanne Simpson's career – the first fifty yearS. *Bull. Amer. Meteor. Soc.*, 81, 2463-2474.

Tao, W. K., S. Lang, J. Simpson, W. S. Olson, D. Johnson, B. Ferrier, C. Kummerow and R. Adler, Vertical profiles of latent heat release and their retrieval for TOGA COARE convective systems using a cloud resolving model, SSM/I and ship-borne radar data. *J. Meteor. Soc. Japan*, 78, 333-355.

Tokay, A., R. Chamberlain and M. Schoenhuber, Laboratory and field measurements of raindrop oscillations. *Physics and Chemistry of the Earth. Part B-Hydrology Oceans and Atmosphere.* 25, 867-870.

Tuttle, J., R. Carbone and J.-J. Wang, Trade wind rainfall near the windward coast of Hawaii: Corrected data yield improved results. *Mon. Wea. Rev.*, 128, 896-900.

Viltard, N., C. Kummerow, W.S. Olson, Y. Hong, 2000: Combined use of the radar and radiometer of TRMM to estimate the influence of drop size distribution on rain retrievals. *J. Appl. Meteor.*, **39**, 2103-2114.

Wang, J.-J., R. M. Rauber, H. T. Ochs and R. Carbone, The effects of the island of Hawaii on offshore rainband evolution. Mon. Wea. Rev., 128, 1052-1069.

Welton, E. J., K. J. Voss, H. R. Gordon, H. Maring, A. Smirnov, B. Holben, B. Schmid, J. Livingston, P. Russell, P. Durkee, P. Formenti and M. O. Andreae, Ground-based lidar measurements of aerosols during ace-2: Instrument description, results and comparisons with other ground-based airborne measurements. Tellus B, 52, 635-650.

Williams, C. R., A. Kruger, K. S. Gage, A. Tokay, R. Cifelli, W. F. Krajewski and C. Kummerow, Comparison of simultaneous rain drop size distributions estimated from two surface disdrometers and a UHF profiles. Geophys. Res. Lett., 27, 1763-1766.

Williams, C.R., P.E. Johnston, W.L. Eckland, R. Cifelli, A. Tokay, D.A. Carter, 2000: Doppler radar profilers as calibration tools for scanning radars. *J. Appl. Meteor.*, **39**, 2209-2222.

Yang, S. and E.A. Smith, 2000: Vertical structure and transient behavior of convective-stratiform heating in TOGA-COARE from combined satellite-sounding analysis. *J. Appl. Meteor.*, **39**, 1491-1513.

CLIMATE AND RADIATION BRANCH

Alpert, P., J. Herman, Y. J. Kaufman and I. Carmona, Response of the climatic temperature to dust forcing, inferred from total ozone mapping spectrometer (TOMS) aerosol index and the NASA assimilation model. *J. Atmos. Res.*, 53, 13-14.

Artaxo, P. R.C. de Campos, E.T. Fernandes, J.V. Martins, Z. Xiao, O. Lindqvist, M.T. Fernandez-Jimenez, W. Maenhaut, Large scale mercury and trace element measurements in the Amazon Basin. *Atmos. Environ.*, **34**, 4085-4096.

Baode C. and M. Yanai, Comparison of the Madden-Julian oscillation (MJO) during the TOGA-COARE IOP with a 15-year climatology. the TOGA-COARE IOP with a 15-year climatology. *J. Geophys. Res.*, 105, 2139-2149.

Baum, B. A., D. P. Kratz, P. Yang, S. C. Ou, Y. Hu, P. Soulen and S. C. Tsay, Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS 1. Data and Models. *J. Geophys. Res.*, 105, 11767-11780.

Baum, B. A., P. F. Soulen, K. I. Strabala, M. D. King, S. A. Ackerman, W. P. Menzel and P. Yang, Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS 2. Cloud thermodynamic phase. *J. Geophys. Res.-Atmos.*, 105, 11781-11792.

Bell, T. L. and P. K. Kundu, Dependence of satellite sampling error on monthly averaged rain rates: Comparison of simple models and recent studies. *J. Climate*, 13, 449-462.

Chao, W. C., Multiple quasi-equilibria of the ITCZ and the origin of monsoon onset. *J. Atmos., Sci.*, 57, 641-652.

Chiapello, I., P. Goloub, D. Tanré, A. Marchand, J. Herman and O. Torres, Aerosol detection by TOMS and POLDER over oceanic regions. *J. Geophys. Res.-Atmos.*, 105, 7133-7142.

Chou, S. H., W. Zhao and M. D. Chou, Surface heat budgets in the Pacific warm pool during TOGA COARE. *J. Climate*, 13, 634-649.

Coakley, J. A., P. A. Durkee, K. Nielsen, J. P. Taylor, S. Platnick, B. A. Albrecht, D. Babb, F. L. Chang, W. R. Tahnk, C. S. Bretherton and P. V. Hobbs, The appearance and disappearance of ship tracks on large spatial scales. *J. Atmos., Sci.*, 57, 2765-2778.

DeFelice, T. P., D. J. Meyer, G. Xian, J. Christopherson and R. F. Cahalan, Landsat-7 reveals more than just surface features in remote areas of the globe. *Bull. Amer. Meteor. Soc.*, 81, 1047-1049.

Demoz, B., D. Starr, D. Whiteman, K. Evans, D. Hlavka and R. Peravali, Raman LIDAR detection of cloud base. *Geophys. Res. Lett.*, 27, 1899-1902.

Dubovik, O., A. Smirnov, B. N. Holben, M. D. King, Y. J. Kaufman, T. F. Eck and I. Slutsker, Accuracy assessment of aerosol optical properties retrieval from AERONET sun and sky radiance measurements. *J. Geophys. Res.*, 105, 9791-9806.

Ducharne, A., R. D. Koster, M. J. Suarez, M. Stieglitz and P. Kumar, A catchment-based approach to modeling land surface processes in a general circulation model. 2. Parameter estimation and model demonstration. *J. Geophys. Res.-Atmos.*, 105, 24823-24838.

Durkee, P. A., R. E. Chartier, A. Brown, E. J. Trehubenko, S. D. Rogerson, C. Skupniewicz, K. E. Nielsen, S. Platnick and M. D. King, Composite ship track characteristics. *J. Atmos. Sci.*, 57, 2542-2553.

Ferrare, R., S. Ismail, E. Browell, V. Brackett, M. Clayton, S. Kooi, S. H. Melfi, D. Whiteman, G. Schwemmer, K. Evans, P. Russell, J. Livingston, B. Schmid, B. Holben, L. Remer, A. Smirnov and P. Hobbs, Comparison of aerosol optical properties and water vapor among ground and airborne lidars and sun photometers during TARFOX. *J. Geophys. Res.*, 105, 9917-9934.

Ghan, S. J., D. Randall, K. Xu, R. Cederwall, D. Cripe, J. Hack, S. Iacobellis, S. Klein, S. Krueger, U. Lohmann, J. Pedretti, A. Robock, L. Rotstayn, R. Somerville, G. Stenchikov, Y. Sud, G. Walker, S. Xie, J. Yio and M. Zhang, A comparison of single column model simulations of summertime midlatitude continental convection. *J. Geophys. Res. Atmos.*, 105, 2091-2124.

Hu, Y. X., B. Weilicki, B. Lin, G. Gibson, S. C. Tsay, K. Stamnes and T. Wong, A fast and accurate treatment of particle scattering phase function with weighted singular-value-decomposition least squares fitting. *J. Quant. Spectrosc. Radiat. Transfer*, 65, 681-690.

Ji, Q. and S.-C. Tsay, On the dome effect of eppley pyrgeometers and pyranometers. *Geophys. Res. Lett.*, 27, 971-974.

Jones, C., D. E. Waliser, J. K. E. Schemm and W. K. M. Lau, Prediction skill of the madden and julian oscillation in dynamical extended range forecasts. *Climate Dynamics*, 16, 273-289.

Kaufman, Y. J., A. Karnieli and D. Tanré, Detection for dust over the deserts using satellite data in the solar wavelengths. *IEEE TGARS*, 38, 525-531.

Kaufman, Y. J., B. N. Holben, D. Tanré, I. Slutsker, A. Smirnov and T. F. Eck, Will aerosol measurements from Terra and Aqua polar orbiting satellites represent the daily aerosol abundance and properties? *Geophys. Res. Lett.*, 27, 3861-3864.

King, M. D. and D. D. Herring, Monitoring Earth's vital signs. *Scientific American*, 282, 92-97.

Kleidman, R. G., Y. J. Kaufman, L. A. Remer, R. A. Ferrare and B. C. Gao, Remote sensing of total precipitable water vapor in the near-IR over ocean glint. *Geophys. Res. Lett.*, 27, 2657-2660.

Koster, R. D., M. J. Suarez and M. Heiser, Variance and predictability of precipitation at seasonal-to-interannual timescales. *J. Hydrometeor.*, 1, 26-46.

Koster, R. D., M. J. Suarez, A. Ducharne, M. Stieglitz and P. Kumar, A catchment-based approach to modeling land surface processes in a general circulation model. 1. Model structure. *J. Geophys. Res.-Atmos.*, 105, 24809-24822.

Knyazikhin, Y. and A. Marshak, 2000: Mathematical aspects of BRDF modeling: Adjoint problem and Green's Function. *Remote Sens. Review*, **18**, 263-280.

Lau, K. M., Y. Ding, J. T. Wang, R. Johnson, T. Keenan, R. Cifelli, J. Gerlach, O. Thiele, T. Rickenbach, S. C. Tsay and P. H. Lin, A report of the field operations and early results of the south china sea monsoon experiment (SCSMEX). *Bull. Amer. Meteor. Soc.*, 81, 1261-1270.

Lau, K. M., K. M. Kim and S. Yang, Dynamical and boundary forcing characteristics of regional components of the Asian summer monsoon. *J. Climate*, 13, 2461-2482.

Liu, L. and B. Chen, Climatic Warming in the Tibetan Plateau during recent decades, Int. *J. Climatology*, 20, 1729-1742.

Li, X., C. H. Sui and K. M. Lau, Interaction between tropical convection and its embedding environment: An energetics analysis of a 2-D cloud resolving simulation. *J. Atmos., Sci.*, 78, 647-659.

Li, X., C.-H. Sui, K. M. Lau and D. Adamec, Effects of precipitation on ocean mixed-layer temperature and salinity as simulated in a coupled ocean-cloud resolving atmosphere model. *J. Meteor. Soc. Japan*, 78, 647-659.

Marshak, A., Y. Knyazikhin, A. B. Davis, W. J. Wiscombe and P. Pilewskie, Cloud-vegetation interaction: Use of normalized difference cloud index for estimation of cloud optical thickness. *Geophys. Res. Lett.*, 27, 1695-1698.

Mehta, V. M., M. J. Suarez, J. V. Manganello and T. L. Delworth, Oceanic influence on the North Atlantic oscillation and associated northern hemisphere climate variations. *Geophys. Res. Lett.*, 27, 121-124.

Mehta, V. and M. J. Suarez, Decadal-multidecadal variations of ENSO: 1909-1988. *J. Geophys. Res. Lett.*, 27, 121-124.

Oreopoulos, L., A. Marshak, R. Cahalan and G. Wen, Cloud 3D effects evidenced in Landsat spatial power spectra and autocorrelation functions. *J. Geophys. Res. Lett.*, 105, 14777-14788.

Oreopoulos, L., R. Cahalan, A. Marshak and G. Wen, A new normalized difference cloud retrieval technique applied to Landsat radiances over the Oklahoma ARM site. *J. Appl. Meteor.*, 39, 2305-2321.

Platnick, S. P., A. Durkee, K. Nielson, J. P. Taylor, S. C. Tsay, M. D. King, R. J. Ferek and P. V. Hobbs, The role of background cloud microphysics in the radiative formation of ship track formation. *J. Atmos. Sci.*, 57, 2607-2624.

Platnick, S., Vertical photon transport in cloud remote sensing problems. *J. Geophys. Res.-Atmos.*, 105, 22919-22935.

Prabhakara, C., R. Iacovazzi, Jr., J. A. Weinman and G. Dalu, A TRMM microwave radiometer rain rate estimation method with convective and stratiform discrimination. *J. Meteor. Soc. of Japan*, 78, 241-258.

Prabhakara, C., R. Iacovazzi, J. M. Yoo and G. Dalu, Global warming: Evidence from satellite observations. *Geophys. Res. Lett.*, 27, 3517-3520.

Rolland, P., K. N. Liou, M. D. King, S. C. Tsay and G. M. McFarquhar, Remote sensing of optical and microphysical properties of cirrus clouds using MODIS channels: I. Methodology and sensitivity to assumptions. *J. Geophys. Res.*, 105, 11,721-11,738.

Smirnov, A., B. N. Holben, O. Dubovik, N. T. O'Neill, L. A. Remer, T. F. Eck, I. Slutsker and D. Savoie, Measurement of atmospheric optical parameters on U.S. atlantic coast sites, ships and Bermuda during TARFOX. *J. Geophy. Res.*, 105, 9887-9902.

Smirnov, A., B. N. Holben, D. Savoie, J. M. Prospero, Y. J. Kaufman, D. Tanré, T. F. Eck and I. Slutsker, Relationship between column aerosol optical thickness and in situ ground based dust concentrations over Barbados. *Geophys. Res. Lett.*, 27, 1643-1646.

Soulen, P. F., S. C. Tsay, M. D. King, G. T. Arnold and J. Y. Li, Airborne spectral measurements of surface-atmosphere anisotropy during the SCAR-A, Kuwait oil fire and TARFOX experiments. *J. Geophys. Res.*, 105, 10203-10218.

Taylor, J. P., M. D. Glew, J. A. Coakley, W. R. Tahnk, S. Platnick, P. V. Hobbs and R. J. Ferek, Effects of aerosols on the radiative properties of clouds. *J. Atmos. Sci.*, 57, 2656-2670.

Varnai, T., Influence of three-dimensional radiative effects on the spatial distribution of shortwave cloud reflection. *J. Atmos. Sci.*, 57, 216-229.

Vega, A. J., R. V. Rohli and C. H. Sui, Climatic relationships to Chesapeake Bay salinity during southern oscillation extremes. *Physical Geography*, 20, 468-490.

Yang, P., K. N. Liou, K. Wyser and D. Mitchell, Parameterization of the scattering and absorption properties of individual ice crystals. *J. Geophys. Res.-Atmos.*, 105, 4699-4718.

Yani, M. and Baode Chen, The Madden-Julian oscillation (MJO) during the TOGA-COARE IOP. *J. Atmos. Sci.*, 57, 2374-2396

ATMOSPHERIC EXPERIMENT BRANCH

Mahaffy, P. R., H. B. Niemann, A. Alpert, S. K. Streya, J. Demick, T. M. Donahue, D. N. Harpold and T. C. Owen, Noble gas abundance and isotope ratios in the atmosphere of Jupiter from the galileo probe mass spectrometer. *J. Geophys. Res.*, 105, 15,061-15,071.

Wolff, C., Linear r-Modes below the Sun's convective envelope. *Astrophys. J.*, 531, 591.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Aikin, A. C. and H. J. P. Smith, Mesospheric odd nitrogen enhancements during relativistic electron precipitation events. *Physics and Chemistry of the Earth Part C-Solar-Terrestrial and Planetary Science*, 25, 203-211.

Allen, D. J., K. Pickering, G. Stenchikov, A. Thompson and Y. Kondo, A three-dimensional total odd nitrogen (NOy) simulation during SONEX using a stretched-grid chemical transport model. *J. Geophys. Res.*, 105, 3851-3876.

Behrendt, A. and J. Reichardt, Atmospheric temperature profiling in the presence of clouds with a pure rotational Raman lidar using an interference-filter-based polychomator. *Appl. Optics.*, **39**, 1372-1378.

Bieberbach, G., H. E. Fuelberg, A. M. Thompson, A. Schmitt, J. R. Hannan, G. L. Gregory, Y. Kondo, R. D. Knabb, G. W. Sachse and R. W. Talbot, Mesoscale numerical investigations of air traffic emissions over the North Atlantic during SONEX flight 8: A case study. *J. Geophys. Res.-Atmos.*, 105, 3821-3832.

Chiapello, I., P. Goloub, D. Tanré, A. Marchand, J. Herman and O. Torres, Aerosol detection by TOMS and POLDER over oceanic regions. *J. Geophys. Res.*, 105, 7133-7142.

Chin, M., D. L. Savoie, B. J. Huebert, A. R. Bandy, D. C. Thorton, T. S. Bates, P. K. Quinn, E. S. Saltzman and W. J. De Bruyn, Atmospheric sulfur cycle simulated in the global model GOCART: Comparison with field observations and regional budgets. *J. Geophys. Res.*, 105, 24,689-24,712.

Chin, M., R. B. Rood, S.-J. Lin, J.-F. Muller and A. M. Thompson, Atmospheric sulfur cycle simulated in the global model GOCART: Model description and global properties. *J. Geophys. Res.*, 105, 24,671-24,687.

Combal, B., S. Oshchepkov, A. Sinyuk, H. Isaka, 2000: Statistical framework of inverse problem in the retrieval of vegetation parameters. *Agronomie*, **20**, 65-77.

Considine, D. B., A. R. Douglass, P. S. Connell, D. E. Kinnison and D. A. Rotman, A polar stratospheric cloud parameterization for the global modeling initiative three-dimensional model and its response to stratospheric aircraft. *J. Geophys. Res.-Atmos.*, 105, 3955-3973.

Cunnold, D. M., M. Newchurch, L. Flynn, H. Wang, J. Russell, R. McPeters, J. Zawodny and L. Froidevaux, Uncertainties in upper stratospheric ozone trends. *J. Geophys. Res.*, 105, 4427 - 4444.

Dessler, A. E., The chemistry and physics of stratospheric ozone. *Academic Press*, 214. Dessler, A. E. and S. C. Sherwood, Simulations of tropical upper tropospheric humidity. *J. Geophys. Res.*, 105, 20,155-20,163.

Flittner, D. E., P. K. Bhartia and B. Herman, 03 profiles retrieved from limb scatter measurements: Theory. *Geophys. Res. Lett.*, 27, 2597-2600.

Folkins, I., S. J. Oltmans and A. M. Thompson, Tropical convection outflow and near-surface equivalent potential temperatures. *Geophys. Res. Lett.*, 27, 2549-2552.

Gettelman, A., J. R. Holton and A. R. Douglass, Simulations of water vapor in the lower stratosphere and upper troposphere. *J. Geophys. Res.-Atmos.*, 105, 9003-9023.

Hannan, J. R., H. E. Fuelberg, A. M. Thompson, G. Bieberbach, R. D. Knabb, Y. Kondo, B. E. Anderson, E. V. Browell, G. L. Gregory, G. W. Sachse and H. B. Singh, Atmospheric chemical transport based on high-resolution model-derived winds: A case study. *J. Geophys. Res.*, 105, 3807-3820.

Herman, J. R., R. D. Piacentini, J. Ziemke, E. Celarier and D. Larko, Interannual variability of ozone and UVB ultraviolet exposure. *J. Geophy. Res.*, 105, 29189-29194.

Hsu, C. N., J. R. Herman and C. Weaver, Determination of radiative forcing of saharan dust using combined TOMS and ERBE data. *J. Geophys. Res.*, 105, 20,649-20,662.

Jackman, C. H., E. L. Fleming and F. M. Vitt, Influence of extremely large solar proton events in a changing stratosphere. *J. Geophys. Res.-Atmos.*, 105, 11,659-11,670.

Jeker, D. P., L. Pfister, A. M. Thompson, D. Brunner, D. J. Boccippio, K. E. Pickering, H. Wernli, Y. Kondo and J. Staehelin, Measurements of nitrogen oxides at the tropopause: Attribution to convection and correlation with lightning. *J. Geophys. Res.-Atmos.*, 105, 3679-3700.

Kalliskota, S., J. Kaurola, P. Taalas, J. R. Herman, E. A. Celarier and N. A. Krotkov, Comparison of daily UV doses estimated from Nimbus 7/TOMS measurements and ground-based spectroradiometric data. *J. Geophys. Res.-Atmos.*, 105, 5059-5067.

Khairullina, A., T. Oleinik, A. Sinyuk, V. Babenko, A. Ponyavina, T. Zhevlakova, 2000: Simulation of scattering of optical radiation by a metal surface with nanometer irregularity. *Opt. Spetrosk.*, **88**, 615-618.

Koike, M., Y. Kondo, G. L. Gregory, B. E. Anderson, G. W. Sachse, D. R. Blake, S. C. Liu, H. B. Singh, A. M. Thompson, K. Kita, Y. Zhao, T. Sugita, R. E. Shetter and N. Toriyama, Impact of aircraft emissions on reactive nitrogen over the North Atlantic flight corridor region. *J. Geophys. Res.-Atmos.*, 105, 3665-3677.

Krotkov, N. A. and A. P. Vasilkov, Reduction of skylight reflection effects in the above-water measurement of diffuse marine reflectance: Comment. *Appl. Optics*, 39, 1379-1381.

Lait, L., Effects of satellite scanning configurations on derived gridded fields. *J. Geophys. Res.-Atmos.*, 105, 9063-9074.

Mayr, H. G., J. G. Mengel, C. A. Reddy, K. L. Chan and H. S. Porter, Properties of QBO and SAO generated by gravity waves. *J. Atmos. Sci. Terr. Phys.*, 62, 1135.

McPeters, R. D., S. Janz, E. Hilsenrath, T. Brown, D. Flittner and D. Heath, The retrieval of ozone profiles from limb scatter measurements: Results from the shuttle ozone limb sounding experiment. *Geophys. Res. Lett.*, 27, 2597-2600.

Meijer, E. W., P. F. J. van Velthoven, A. M. Thompson, L. Pfister, H. Schlager, P. Schulte and H. Kelder, Model calculations of the impact of NOx from air traffic, lightning and surface emissions, compared with measurement. *J. Geophys. Res.-Atmos.*, 105, 3833-3850.

Morris, G. A., J. Ziemke, J. F. Gleason and M. R. Schoeberl, Trajectory mapping: A tool for validation of trace gas observations. *J. Geophys. Res.*, 105, 17,875-17,894.

Nedoluha, G. E., R. M. Bevilacqua, K. W. Hoppel, M. Daehler, E. P. Shettle, J. H. Hornstein, M. D. Fromm, J. D. Lumpe and J. E. Rosenfield, POAM III measurements of dehydration in the Antarctic lower stratosphere. *Geophys. Res. Lett.*, 27, 1683-1686.

Newchurch, M. J., L. Bishop, D. Cunnold, L. E. Flynn, S. Godin, S. H. Frith, L. Hood, A. J. Miller, S. Oltsman, W. Randel, G. Reinsel, R. Stolarski, R. Wang, E. Yang and J. M. Zawodny, Upper-stratospheric ozone trends 1979-1998. *J. Geophys. Res.*, 105, 14625-14636.

Newman, P. A. and E. R. Nash, Quantifying the wave driving of the stratosphere. *J. Geophys. Res.-Atmos.*, 105, 12,485-12,497.

Newman, P. A., D. W. Fahey, W. H. Brune, M. J. Kurylo and S. R. Kawa, Preface. *J. Geophys. Res.*, 104, 26,481-26,496.

Oshchepkov, S., H. Isaka, J. Gayet, A. Sinyuk, F. Auriol, S. Havemann, 2000: Microphysical properties of mixed- phase and ice clouds retrieved from *in situ* airborne "Polar Nephelometer" measurements. *Geophys. Res. Lett.*, **27**, 209-212.

Pesnell, W. D., R. A. Goldberg, C. H. Jackman, D. L. Chenette and E. E. Gaines, Variation of mesospheric ozone during the highly relativistic electron event in May 1992 as measured by the high resolution doppler imager instrument on UARS. *J. Geophys. Res.*, 105, 22,943-22,953.

Petropavlovskikh, I., R. Loughman, J. DeLiusi and B. Herman, A comparison of UV intensities calculated by spherical-atmosphere radiation transfer codes: Application to the aerosol corrections. *J. Geophys. Res.*, 105, 14,737-14,746.

Qin, W. H. and S. Gerstl, 3-D scene modeling of semidesert vegetation cover and its radiation regime. *Remote Sensing of Environment*, 74, 145-162.

Qin, W. and S. Liang, Plane – parallel canopy radiation transfer modeling: Recent advances and future directions. *Rem. Sens. Revs.*, 18, 281-305.

Reichardt, J., A. Tsias, and A. Behrendt, 2000: Optical properties of PSC IA-enhanced at UV and visible wavelengths: Model and observations. *Geophys. Res. Lett.*, **27**, 201-204.

Reichardt, J., S. E. Bisson, S. Reichardt, C. Weitkamp and B. Neidhart, Rotational vibrational-rotational raman differential absorption lidar for atmospheric ozone measurements: Methodology and experiments. *Appl. Optics*, 39, 6072-6079.

Reichardt, J., M. Hess and A. Macke. Lidar inelastic multiple-scattering parameters of cirrus particle ensembles determined with geometrical-optics crystal phase functions. *Appl. Optics*, 39, 1895-1910.

Reichardt, J., Error analysis of raman differential absoprtion lidar ozone measurements in ice clouds. *Appl. Opt.*, 39, 6058-6071.

Sherwood, S. C., A "stratospheric drain" over the maritime continent. *Geophys. Res. Lett.*, 27, 677-680.

Sherwood, S. C, Climate signal mapping and an application to atmospheric tides. *Geophys. Res. Lett.*, 27, 3525-3528.

Sherwood, S. C., On moist stability. *Mon. Wea. Rev.*, 128, 4139-4142.

Sherwood, S. C. and A. E. Dessler, On the control of stratospheric humidity. *Geophys. Res. Lett.*, 27, 2513-2516.

Simpson, I. J., B. C. Sive, D. R. Blake, N. J. Blake, T. Y. Chen, J. P. Lopez, B. E. Anderson, G.W. Sachse, S. A. Vay, H. E. Fuelberg, Y. Kondo, A. M. Thompson and F. S. Rowland, Nonmethane hydrocarbon measurements in the North Atlantic flight corridor during the subsonic assessment ozone and nitrogen oxide experiment. *J. Geophys. Res.-Atmos.*, 105, 3785-3793.

Sparling, L. C., Statistical perspectives on stratospheric transport. *Rev. Geophys.*, 38, 417-436.

Steinbrecht, W., R. Neuber, P. von der Gathen, P. Wahl, T. J. McGee, M. R. Gross, U. Klein and J. Langer, Results of the 1998 ny-alesund ozone monitoring intercomparison. *J. Geophys. Res.-Atmos.*, 104, 30515-30523.

Taalas, P., J. Kaurola, A. Kylling, D. Shindell, R. Sausen, M. Dameris, V. Grewe, J. Herman, J. Damski and B. Steil, The impact of greenhouse gases and halogenated species on future solar UV radiation doses. *Geophys. Res. Let.*, 27, 1127-1130.

Tabazadeh, A., M. L. Santee, M. Y. Danilin, H. C. Pumphrey, P. A. Newman, P. J. Hamill and J. L. Mergenthaler, Quantifying denitrification and its effect on ozone recovery. *Science*, 288, 1407-1411.

Thompson, A. M., B. G. Doddridge, J. W. Witte, R. D. Hudson, W. T. Luke, J. E. Johnson, B. J. Johnson, S. J. Oltmans and R. Weller, A tropical Atlantic paradox: Shipboard and satellite views of a tropospheric ozone maximum and wave-one in January-February 1999. *Geophys. Res. Lett.*, 27, 3317-3320.

Thompson, A. M., H. B. Singh and H. Schlager, Introduction to special section: Subsonic assessment ozone and nitrogen oxide experiment (SONEX) and pollution from aircraft emissions in the North Atlantic flight corridor (POLINAT 2). *J. Geophys. Res.*, 105, 3595-3603.

Tsou, J. J., B. J. Connor, A. Parrish, R. B. Pierce, I. S. Boyd, G. E. Bodeker, W. P. Chu, J. M. Russell, D. P. J. Swart and T. J. McGee, NDSC millimeter wave ozone observations at Lauder, New Zealand, 1992-1998: Improved methodology, validation, and variation study. *J. Geophys. Res.-Atmos.*, 105, 24263-24281.

Vitt, F. M., T. E. Cravens and C. H. Jackman, A two-dimensional model of thermospheric nitric oxide sources and their contributions to the middle atmospheric chemical balance. *J. Atmos. Sol.-Terr. Phys.*, 62, 653-667.

Vitt, F. M., T. P. Armstrong, T. E. Cravens, G. A. M. Dreschhoff, C. H. Jackman and C. M. Laird, Computed contributions to odd nitrogen concentrations in the Earth's polar middle atmosphere by energetic charged particles. *J. Atmos. Sol.-Terr. Phys.*, 62, 669-683.

Wang, Y., S. C. Liu, B. E. Anderson, Y. Kondo, G. L. Gregory, G. W. Sachse, S. A. Vay, R. Blake, H. B. Singh and A. M. Thompson, Evidence of convection as a major source of condensation nuclei in the northern midlatitude upper troposphere. *Geophys. Res. Lett.*, 27, 369-372.

Weatherhead, E. C., G. C. Reinsel, G. C. Tiao, C. H. Jackman, L. Bishop, S. M. Hollandsworth Frith, J. DeLiusi, T. Keller, S. J. Oltmans, E. L. Fleming, D. J. Wuebbles, J. B. Kerr, A. J. Miller, J. R. Herman, R. D. McPeters, R. M. Nagatani and J. E. Frederick, Detecting the recovery of total column ozone. *J. Geophys. Res.*, 105, 22,201-22,210.

Weaver, C. J., A. R. Douglass and R. B. Rood, Lamination frequencies as a diagnostic for horizontal mixing in a 3D transport model. *J. Atmos. Sci.*, 57, 247-261.

Ziemke, J. R., S. Chandra and P. K. Bhartia, A new NASA data product: Tropospheric and stratospheric column ozone in the tropics derived from TOMS measurements. *Bull. Amer. Meteor. Soc.*, 81, 580-583.

Ziemke, J. R., S. Chandra, J. Herman and C. Varotsos, Erythemally weighted UV trends over northern latitudes derived from Nimbus 7 TOMS measurements. *J. Geophys. Res.-Atmos.*, 105, 7373-7382.

APPENDIX 8. AWARDS/HONORS/MEMBERSHIPS

LABORATORY FOR ATMOSPHERES

Mark Schoeberl:

Group achievement award for SOLVE .

NASA Distinguished Service Medal for Earth Science Vision.

Excellence in Outreach Award for UARS Movie and Brochure.

UARS Project Science Team award for developing educational and outreach materials for UARS.

DATA ASSIMILATION OFFICE

Steve Cohn:

Associate Editor, Monthly Weather Review.

Steven Pawson:

Editor: Journal of Geophysical Research, Atmospheres.

Richard B. Rood:

NASA Outstanding Leadership Medal.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Dean Duffy:

Editor, Monthly Weather Review.

Fritz Hasler:

2000 NASA Excellence in Outreach Award.

Matthew McGill:

Recipient of the James Kerley Award for technology transfer/ commercialization.

Wei-Kuo Tao:

Fellow, Royal Meteorological Society.

Fellow, American Meteorological Society.

Guest Editor, AMS Meteorological Monographs - Symposium on Cloud Systems, Hurricanes and TRMM.

Editor, AMS Journal of Atmospheric Sciences.

CLIMATE AND RADIATION BRANCH

Ming-Dah Chou:

Associate Editor, Journal of the Atmospheric Sciences.

Fellow, American Meteorological Society.

NASA Medal for Exceptional Service.

C.-H. Sui:

Associate Editor, Journal of Climate.

Yoram Kaufman:

Medal for outstanding Scientific Achievement Award from the Aeronautic Society for the Terra mission as outstanding space mission of the year.

NASA Medal for Scientific Achievement.

The Earth Observatory won a "Distinguished" Award from the Society for Technical Communication (STC) in their International On-line Communications Competition.

Terra was nominated to receive an award from Popular Science magazine as "Best Scientific Achievement in 2000."

Max Suarez:

Assistant editor for QJRMS Special issue.

ATMOSPHERIC EXPERIMENT BRANCH

John Haberman:

Certificate for Outstanding Volunteer from the Prince George's County Public Schools.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Arthur Aikin:

Co-editor of Special Issue of Physics and Chemistry of the Earth.

Randy Kawa:

NASA Aeronautics Certificate of Recognition for contribution to High Speed Research Program.

Paul Newman:

Group achievement award for SOLVE.

JGR Associate Editor

Anne Thompson:

Elected as a Councilor (executive board member) of the American Meteorological Society. Three-year term to begin at the Annual Meeting in January 2001.

APPENDIX 9. ACRONYMS

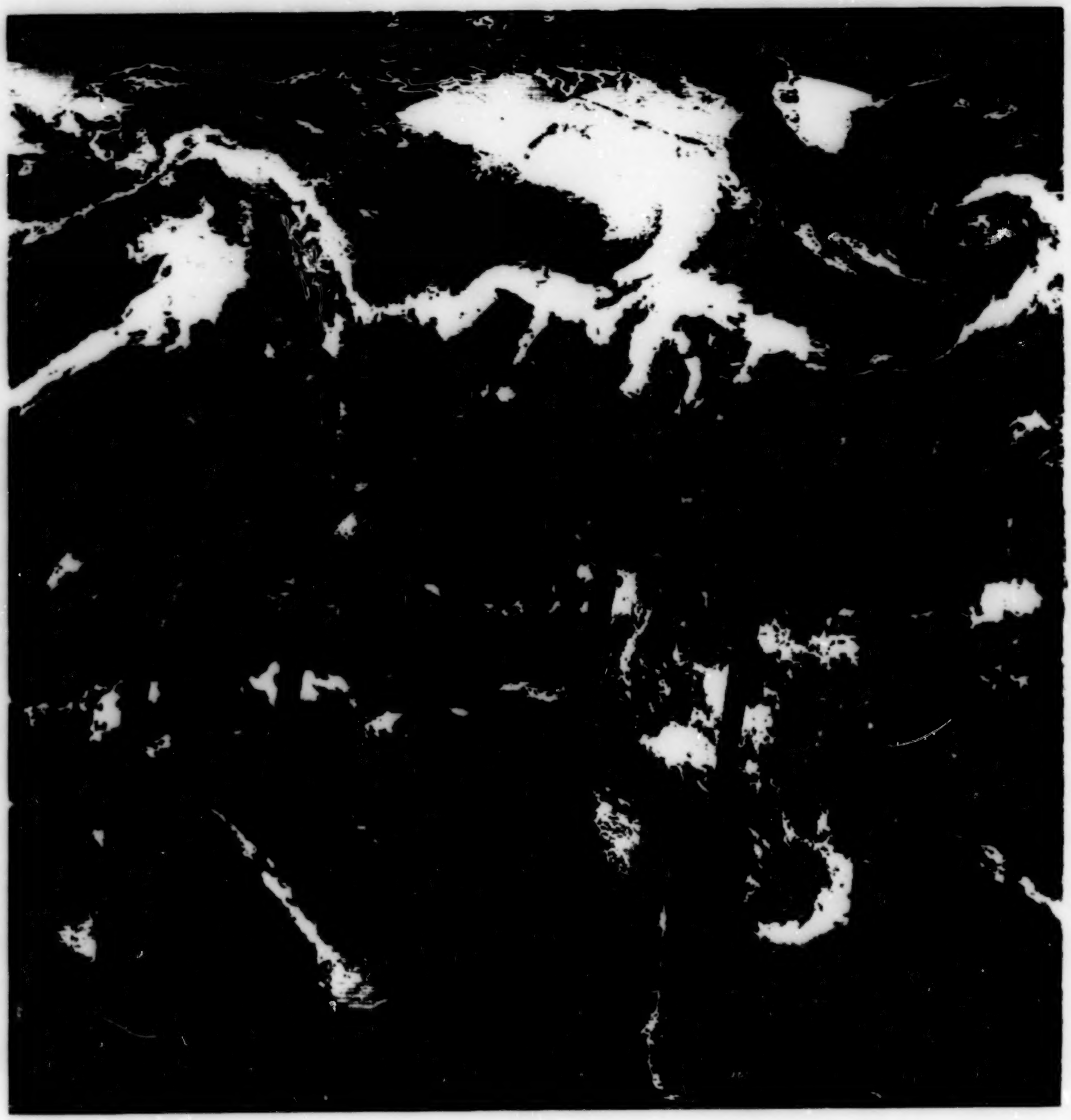
ACCENT	Atmospheric Chemistry of Combustion Emissions Near the Tropopause
ACE-Asia	Aerosol Characterization Experiment-Asia
AERONET	Aerosol Robotic Network
AETD	Applied Engineering and Technology Directorate
AIRS	Atmospheric Infrared Sounder
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
AROTEL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ARM	Atmospheric Radiation Measurement
ARREX	Aerosol Recirculation and Rainfall Experiment
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMS	Advanced Technology Microwave Sounder
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BUV	backscatter ultraviolet
CAN	Cooperative Agreement Notice
CCAST	Cooperative Center for Atmospheric Science and Technology
CCD	Convective Cloud Differential
CCM4	Community Climate Model version 4
CEAS	Center for Earth-Atmosphere Studies
CERES	Clouds and the Earth's Radiant Energy System
CFCs	chlorofluorocarbons
CHARC	CSTEA HBCU Academic and Research Consortium
CHyMERA	Compact Hyperspectral Mapper for Environmental Remote Sensing Applications
CIFAR	Cooperative Institute for Atmospheric Research
CIMEL	Sun Photometer (French word)
CLIVAR	Climate Variability and Predictability Programme
CNES	Center Nationale d'Etude Spatiales
Co-I	Co-Investigator
CONTOUR	Comet Nucleus Tour
COVIR	Compact Vis IR
CPL	Cloud Physics Lidar
CrIS	Crosstrack Infrared Sounder
CRM	Cloud Resolving Model
CRS	Cloud Radar System
CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
DAAC	Distributed Active Archive Center
DAO	Data Assimilation Office
DAS	Data Assimilation System
DDF	Director's Discretionary Fund
DIAL	Differential Absorption Lidar
DISS	Distributed Image Spreadsheet
DMSP	Defense Meteorological Satellite Program
ECSO	Executive Committee for Science Outreach
EDOP	ER-2 Doppler Radar
EDR	Environmental Data Record

EI	El Niño Index
ENSO	El Niño Southern Oscillation
ENVISAT	Environmental Satellite
EOS	Earth Observing System
EPIC	Earth Polychromatic Imaging Camera
ERBE	Earth Radiation Budget Experiment
ESA	European Space Agency
ESE	Earth Science Enterprise
ESPI	ENSO Precipitation Index
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth Systems Science Pathfinder
E-Theater	Electronic Theater
EUV	extreme ultraviolet
FFPA	filter/focal plane array
4DDA	four-dimensional data assimilation
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GCMS	Gas Chromatograph Mass Spectrometer
GCRP	Global Change Research Program
GEOS	Goddard Earth Observing System
GEST Center	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GLAS	Geoscience Laser Altimeter System
GLOBE	Global Learning and Observations to Benefit the Environment
GLOW	Goddard Lidar Observatory for Winds
GMI	Global Modeling Initiative
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GoHFAS	Goddard Howard University Fellowship in Atmospheric Sciences
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Mission
GPMS	Galileo Probe Mass Spectrometer
GPS	Global Positioning Satellite
GSFC	Goddard Space Flight Center
GTWS	Global Tropospheric Wind Sounder
GUV	Ground-based Ultraviolet Radiometer
GV	Ground Validation
GVP	Ground Validation Program
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HBCUs	Historically Black Colleges and Universities
HDTV	High Definition TV
HIRS	High Resolution Infrared Sounder
HOTS	Holographic Optical Telescope and Scanner
HPCC	High Performance Computing and Communications
HSB	Humidity Sounder Brazil
HSCT	High-Speed Civil Transport
HUPAS	Howard University Program in Atmospheric Sciences
IAP	Independent Activity Period course
IGS	Internal Government Studies

IIP	Instrument Incubator Program
INDOEX	Indian Ocean Experiment
INMS	Ion and Neutral Mass Spectrometer
IORD	Integrated Operational Requirements Document
IPO	Integrated Program Office
IR	infrared
ISAS	Institute of Space and Aeronautical Science
ISCCP	International Satellite Cloud Climatology Project
ISIR	IR Spectrometer Imaging Radiometer
ITCZ	Intertropical Convergence Zone
JARG	Joint Agency Requirements Group
JCET	Joint Center for Earth Systems Technology
JCG	Joint Center for Geoscience
JCOSS	Joint Center for Observation System Science
JCSDA	Joint Center for Satellite Data Assimilation
JPL	Jet Propulsion Laboratory
KWAJEX	Kwajalein Experiment
LARS	Lidar Atmospheric Raman Spectrometer
LAS	Leonardo Airborne Simulator
LASAL	Large Aperture Scanning Airborne Lidar
LI	La Niña Index
LSM	Land Surface Model
MBA	microbolometer array
MEIDEX	Mediterranean Israeli Dust Experiment
MISR	Multi-Angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MM5	Mesoscale Model 5
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
MPL	Micro Pulse Lidar
MSU	Microwave Sounding Unit
NAS	Numerical Aerospace Simulation
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Computational Sciences
NCEP	National Center for Environmental Prediction
NDSC	Network for the Detection of Stratospheric Change
NESDIS	National Environmental Satellite Data and Information Service
NEWMAST	NASA Educational Workshop for Secondary Math, Sciece, and Technology Teachers
NGI	Next Generation Internet
NGIMS	Neutral Gas and Ion Mass Spectrometer
NIIEM	Russian Scientific Research Institute of Electromechanics
NIST	National Institutes of Standards and Technology
NMNH	National Museum of Natural History
NMS	Neutral Mass Spectrometer
NOAA	National Oceanic Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System

NPP	NPOESS Preparatory Project
NRC	National Research Council
NSES	National Science Education Standards
NSF	National Science Foundation
NSIPP	NASA Seasonal-to-Interannual Prediction Project
NTSC	National Television Standards Committee
OAT	Operation Algorithm Team
ODIN	a Swedish small satellite project for astronomical and atmospheric research
OLR	Outgoing Longwave Radiation
OMPS	Ozone Mapper and Profiler System
OSIRIS	ODIN Spectrometer and IR Imager System
OSR	outgoing shortwave radiation
OSSE	Observing System Simulation Experiment
PI	Principal Investigator
PICASSO-CENA	Pathfinder Instruments for Cloude and Aerosol Spaceborne Observations-Climatologie Etendue des Nuages et des Aerosols
PLACE	Parameterization for Land Atmosphere Cloud Exchange
PRiDE	Puerto Rico Dust Experiment
POES	Polar Orbiting Environmental Satellite
PSAS	Physical-space Statistical Analysis System
QuikSCAT	scatterometer satellite
QuikTOMS	spacecraft rapidly developed by Orbital Sciences Corp. to carry TOMS-5
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RELACS	Regional Land-Atmosphere Climate Simulation System
RSAS	Rayleigh Scattering Altitude Sensor
SAFARI	Southern Africa Fire-Atmosphere Research Initiative
SAGE	Stratospheric Aerosol and Gas Experiment
SAVE	Southern African Validation Experiment
SBIR	Small Business Innovative Research
SBUV/2	Solar Backscatter Ultraviolet/version 2
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCO	stratospheric column ozone
SCSMEX	South China Sea Monsoon Experiment
SeaWiFS	Sea-viewing Wide Field-of-View Sensor
SHADOZ	Southern Hemisphere ADditional OZonesondes
SHARP	Summer High School Apprenticeship Research Program
SMART	Surface Measurements for Atmospheric Radiative Transfer
SMiR	Scanning Microwave Radiometer
SOAT	Sounder Operation Algorithm Teams
SOLSE/LORE	Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SONEX	Sass Ozone and Nitrogen oxides EXperiment
SORCE	SOlar Radiation and Climate Experiment
SPARCLE	South Pole Atmospheric Radiation and Cloud Lidar Experiment
SRL	Scanning Raman Lidar
SSM/I	Special Sensor Microwave Imager
SST	sea surface temperature

SSU	Spectral Sensor Unit
STAAC	Systems, Technology, and Advanced Concepts Directorate
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
TCO	tropospheric column ozone
THESEO	Third European Stratospheric Experiment on Ozone
THOR	cloud THickness from Offbeam Returns
3S	Sun-Sky-Surface photometer
TIROS	Televised Infrared Operational Satellite
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TOGA-COARE	Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOMS-CAM	Total Ozone Mapping Spectrometer Camera
TOMS-EP	Total Ozone Mapping Spectrometer-Earth Probes
TOVS	TIROS Operational Vertical Sounder
TPW	total precipitable water
TRMM	Tropical Rainfall Measuring Mission
TSDIS	TRMM Science Data and Information System
UARS	Upper Atmosphere Research Satellite
UCLA	University of California - Los Angeles
UMBC	University of Maryland Baltimore County
UMCP	University of Maryland College Park
USGCRP	US Global Change Research Program
USRA	Universities Space Research Association
UV	ultraviolet
VAL	Visualization Analysis Laboratory
WCRP	World Climate Research Programme



NP-2001-4-214-GSFC

END